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Practical Demonstration of Urban Air Quality Simulation Models - Part II

NATO Committee on the Challenges of Modern Society, Brussels (Belgium)

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COMMITTEE ON
THE CHALLENGES OF
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PRACTICAL DEMONSTRATION OF MULTIPLE SOURCES URBAN AIR QUALITY

Number 106

Part II

NORTH ATLANTIC TREATY ORGANIZATION

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16. ABSTRACT

Part II of this document presents the most important full length original papers prepared during the "Practical Demonstration of Urban Air Quality Simulation Models." It includes the "Common Data Base for the Test-City" which was used for the model claculations, brief descriptions of the different models used in the "Practical Demonstration," and the results of the model calculations for the "Test City."

This document surveys a variety of well-known Gaussian plume models in widespread use and notes the differences between them. It also suggests explanations for the possible band width in model results that may be caused by such differences.

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Practical Demonstration of Urban Air Quality Simulation Models
- Part II -

A Report of the NATO/CCMS Pilot Study on Air Pollution Assessment Methodology and Modeling

COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY
NORTH ATLANTIC TREATY ORGANIZATION
(DECEMBER 1978)

Preface

The North Atlantic Treaty Organization (NATO) established the "Committee on the Challenges of Modern Society" (CCMS) at the November 1969 meeting of the North Atlantic Council.

The CCMS was charged with developing meaningful environmental and social programs that complement other international programs, and with showing leadership, first, in solution of existing problems and, second, in development of long-range goals for environmental protection in the NATO sphere of influence and in other countries as well. A first Pilot Study on Air Pollution was initiated by the CCMS at its inaugural meeting in December 1969. The United States (Environmental Protection Agency) has been the pilot nation with the Federal Republic of Germany (Federal Ministry of the Interior) and Turkey (Scientific and Technical Research Council) as copilot-nations.

The Pilot Study on Air Pollution was an action program designed to demonstrate and encourage the utilization of existing knowledge for the development of air quality management programs. It entailed the demonstration of a system approach to air quality management. Case studies have been carried out in Ankara, Turkey; Frankfurt, Federal Republic of Germany; St. Louis, U. S.; Oslo, Norway; South Holland Region, The Netherlands (NATO/CCMS Report No. 6, Appendices A - E).

The results of the pilot study are documented in NATO/CCMS Report No. 6 (Revised) "Guidelines to Assessment of Air Quality" of October 1972 and in NATO/CCMS Report No. 33 (Final Report) containing 15 recommendations as well as in several other documents, listed as Annex II to this document.

Starting from three of the above recommendations (VI, VII and XIV) the Federal Republic of Germany proposed to initiate a new Pilot Study on Air Pollution Assessment Methodology and Modeling at the CCMS Plenary Session on October 22 and 23, 1974.

These NATO/CCMS Recommendations are:

RECOMMENDATION IV

Member nations will co-operate to develop standardized methods for emissions data storage and retrieval to support requirements in the conduct of national air quality management programs. The US National Emission Data System (NEDS) might serve as a model for a common international system.

RECOMMENDATION VII

Member nations will co-operate to develop standardized techniques for projecting emissions and predicting future ambient air quality.

RECOMMENDATION XIV

Member nations agree the CCMS modeling activity has shown that there is a widespread need for further international co-operation to accomplish the following tasks:

Bring together model developers and air quality managers for exchange of ideas, discussion of users' needs and demonstration of modeling techniques.

Standardize modeling techniques for specific air quality management applications and consider how computerized models might be made available for all users.

Continue to review on-going air quality assessment studies.

In spring 1975 the North Atlantic Council approved the German proposal. The pilot study work started with the Federal Republic of Germany (Federal Ministry of the Interior) as pilot nation and the United States of America (Environmental Protection Agency) and Belgium (Service du Premier Ministre) as co-pilot nations:
A Working Group and two Panels were established with the following functions:

Assessment Methodology Panel

- Pursue and carry out Recommendations VI and VII
- Continue to review present and future assessment studies with respect to the application of assessment methodology.

Modeling Panel

- Develop standardized models for various air quality management applications.
- Develop programs to improve modeler/user communications in conjunction with the Assessment Methodology Panel and the Working Group.
- Continue as an information forum on new modeling concepts and techniques, organizing once a year international technical meetings on air pollution modeling and its application.

In addition the Working Group established an Ad-Hoc Group on Air Quality Management Systems to revise and update the NATO/CCMS Report No. 6 (Revised) 1972 by preparing a new document on "Guidelines to Air Quality Management Systems".

Another Ad-Hoc Group was set up for compiling a Glossary of Terms frequently used in assessment methodology, modeling and air quality management systems.

As an outcome of this Pilot Study on Air Pollution Assessment Methodology and Modeling the following NATO/CCMS documents are published (see also Annex III):

Air Quality Management System

- Guidelines to Air Quality Management System.

Assessment Methodology

- Air Pollution Emission Inventory Systems
- Air Pollution Emissions Projecting

Air Pollution Modeling

- Introduction to Air Quality Modeling
- Uses and Needs for Air Quality Modeling
- Bibliography on Grey Literature on Air Quality Modeling, Part I (Applied Models)
- Bibliography on Grey Literature on Air Quality Modeling, Part II (New Modeling Techniques)
- Practical Demonstration of Multiple Source Urban Air Quality Modeling (Gaussian Plume)
- Fundamentals for the Applications of a Gaussian Plume Model

Other Publications

- Glossary of Terms
- Proceedings of the 6th International Technical Meeting on Air Pollution Modeling and its Application (24. - 26. September 1975, Frankfurt/Main, Germany)
- Proceedings of the 7th International Technical Meeting on Air Pollution Modeling and its Application (7. - 10. September 1976, Airlie House, USA)
- Proceedings of the 8th International Technical Meeting on Air Pollution Modeling and its Application (20. - 23. September 1977, Louvain-la-Neuve, Belgium).

The chairman of the Working Group wishes to acknowledge the scientists participating from pilot, copilot, and observer countries, and the many other persons, who assisted in the preparation of this document.

The panel, which performed diligently throughout the course of this effort, receives the highest praise. The panel members were:

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The addresses of the panel members are listed in Annex I.

Full recognition is given to each panel member for carrying out and coordinating review and other activities related to the development of this document in his respective country and to Ms. C. Morawa of the Federal Environmental Office, Germany for her effort in coordinating and organising and for editorial work.

For the Working Group,
Erich Weber, Chairman.

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2. Introduction

The purpose of Part II of this document is to present in full length the most important original papers which have been prepared when carrying-out the "Practical Demonstration of Urban Air Quality Simulation Models".

It encloses

- the "Common Data Base for the Test-City", which has been used for model calculations,
- brief descriptions of the different models participating in the "Practical Demonstration",
- results of model calculations for the "Test-City".

This document addresses to those users of Gaussian plume models who want to get deeper insight into different Gaussian plume models with the aim to get

- an overview over a variety of well-known models being in widespread operational use,
- an impression of the main differences between different Gaussian plume models,
- a feeling for the possible band width in model results which might be caused by such differences.

Questions like these may only be answered by looking upon such detailed informations as given in Part II of this document.

A survey of capabilities, applicability and limitations of a Gaussian plume model is given in the NATO/CCMS document "Fundamentals for the Application of a Gaussian Plume Model" (see also Annex III).

A review of the variety of applications of Gaussian plume models is outlined in the NATO/CCMS document "Current Needs and Uses of Air Quality Models".

3. Practical Demonstration

3.1 Common Data Base for the "Test-City" (without emission data)

The stability classes by TURNER

Three-dimensional frequency distributions of TURNER-stability-classes, wind speeds, and wind directions

The stability classes by KLUG/MANIER

Statistics of KLUG/MANIER stability-classes

SO_2-emission inventory for residential combustion and industrial sources

The stability classes by TURNER

(from: D. B. TURNER J. Appl. Met. 3 (1964), 83-91
A diffusion model for an urban area)

A stability classification based on hourly airport observations

This system of classifying stability on an hourly basis for research in air pollution is based upon work accomplished by Dr. F. Pasquill of the British Meteorological Office (1961). Stability near the ground is dependent primarily upon net radiation and wind speed. Without the influence of clouds, insolation (incoming radiation) during the day is dependent upon solar altitude, which is a function of time of day and time of year. When clouds exist their cover and thickness decrease incoming and outgoing radiation. In this system insolation is estimated by solar altitude and modified for existing conditions of total cloud cover and cloud ceiling height. At night estimates of outgoing radiation are made by considering cloud cover. This stability classification system has been made completely objective so that an electronic computer can be used to compute stability classes. The stability classes are as follows: 1) Extremely unstable, 2) Unstable, 3) Slightly unstable, 4) Neutral, 5) Slightly stable, 6) Stable, 7) Extremely stable. Table A-1 gives the stability class as a function of wind speed and net radiation. The net radiation index ranges from 4, highest positive net radiation (directed toward the ground), to −2, highest negative net radiation (directed away from the earth). Instability occurs with high positive net radiation and low wind speed, stability with high negative net radiation and light winds, and neutral conditions with cloudy skies or high wind speeds.

The net radiation index used with wind speed to obtain stability class is determined by the following procedure:

1) If the total cloud cover is 10/10 and the ceiling is less than 7000 feet, use net radiation index equal to 0 (whether day or night).
2) For night-time (between sunset and sunrise):
   a) If total cloud cover ≤ 4/10, use net radiation index equal to −2.
   b) If total cloud cover > 4/10, use net radiation index equal to −1.
3) For daytime:
   a) Determine the insolation class number as a function of solar altitude from Table A-2.
   b) If total cloud cover ≤ 5/10, use the net radiation index in Table A-1 corresponding to the insolation class number.
   c) If cloud cover > 5/10, modify the insolation class number by following these six steps.
      1) Ceiling < 7000 ft, subtract 2.
      2) Ceiling ≥ 7000 ft but < 16,000 ft, subtract 1.
      3) Total cloud cover equal 10/10, subtract 1. (This will only apply to ceilings ≥ 7000 ft since cases with 10/10 coverage below 7000 ft are considered in item 1 above.)
      4) If insolation class number has not been modified by steps (1), (2), or (3) above, assume modified class number equal to insolation class number.
      5) If modified insolation class number is less than 1, let it equal 1.
      6) Use the net radiation index in Table A-1 corresponding to the modified insolation class number.

Since urban areas do not become as stable in the lower layers as non-urban areas, stability classes that were computed as 6 and 7 by this system were called class 5 for use with this diffusion model for Nashville, Tenn.

TABLE A-1. Stability class as a function of net radiation and wind speed.

Wind speed (knots)	Net radiation index 4	3	2	1	0	−1	−2
0, 1	1	1	2	3	4	6	7
2, 3	1	2	2	3	4	6	7
4, 5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8, 9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
>12	3	4	4	4	4	4	4

TABLE A-2. Insolation as a function of solar altitude

Solar altitude (a)	Insolation	Insolation class number
60° < a	strong	4
35° < a ≤ 60°	moderate	3
15° < a ≤ 35°	slight	2
a ≤ 15°	weak	1

Three-Dimensional Frequency Distributions of TURNER-Stability-Classes, Wind Speeds, and Wind Directions

The meteorological statistics, which can be found in the following tables, are based on three-hourly observations in the "Test-City" for the time period August 1971 to July 1972.

List of Tables:

Table 1: Total number of observations in the "Test-City" for the time period August 1971 to July 1972; relative frequency of calms and of variable wind directions; mean wind speed in knots.

Table 2,3: Coupled frequency distribution of wind speed (in knots) and of wind direction (in 10 degrees).

Table 4-8: Coupled frequency distribution of wind speed and of wind direction for the seven TURNER-classes. To compensate for the more than random frequency of even values for wind speeds and for the more than random frequency of the main wind directions the following smoothing procedure has been applied

$$H_{i,j} = (H_{i-1,j} + H_{i+1,j} + H_{i,j} + H_{i,j-1} + H_{i,j+1})/5$$

(i: wind speed index;
j: wind direction index).

TEST-CITY

Time Period:	August 1971 to July 1972
Number of Values:	2882
Frequency of calms:	4.61 %
Frequency of winds with variable direction:	2.39 %
Mean wind speed:	6 kn

FREQUENCY DISTRIBUTION OF WIND SPEED AND DIRECTION

WIND DIRECTION IN DEGREES

WIND SPEED	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1	1.6	2.4	2.5	3.6	4.7	5.3	4.0	3.0	3.5	2.9	2.4	2.1	1.7	1.3	1.0	1.6	2.5	3.5
2	2.3	2.6	4.2	5.2	6.5	7.1	4.4	3.7	3.7	3.3	2.2	2.5	1.4	1.0	1.4	1.4	2.1	3.5
3	2.5	4.5	5.7	7.4	9.4	9.6	6.9	4.3	4.2	3.0	2.3	2.0	1.4	0.6	0.9	1.1	1.3	1.3
4	3.6	4.4	6.4	6.1	9.5	9.1	6.3	4.1	3.3	2.2	1.4	1.7	0.6	0.5	0.9	0.6	0.6	2.5
5	1.9	4.5	4.6	6.2	9.0	8.7	4.9	3.9	3.2	2.4	1.2	1.0	0.5	0.4	0.4	0.6	1.2	2.3
6	1.8	2.9	5.4	6.2	8.1	5.7	3.1	2.3	2.7	1.5	0.7	0.6	0.6	0.3	0.4	0.6	0.9	2.7
7	1.2	2.7	3.5	4.2	4.0	3.3	1.9	1.7	1.2	0.8	0.6	0.3	0.3	0.4	0.1	0.1	0.5	1.2
8	1.4	2.8	3.5	3.7	2.9	2.0	1.4	1.0	0.8	1.1	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.7
9	1.2	3.0	3.5	3.7	2.2	1.4	0.8	0.7	1.0	0.6	0.7	0.2	0.1	0.2	0.2	0.2	0.2	0.4
10	1.5	2.9	3.5	3.0	1.8	0.7	0.3	0.4	0.3	0.5	0.2	0.3	0.1	0.0	0.0	0.1	0.1	0.4
11	1.0	2.6	2.8	2.1	0.6	0.4	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.0	0.0	0.0	0.1	0.2
12	0.8	2.4	3.1	2.0	1.2	0.2	0.3	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.2
13	0.7	1.7	2.2	2.2	0.8	0.5	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
14	0.2	1.0	1.2	0.9	0.6	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
15	0.3	0.8	1.0	0.9	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.2	0.8	1.0	0.9	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.1	0.7	0.6	1.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.1	0.3	0.6	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

IN KNOTS

WIND DIRECTION IN DEGREES

WIND SPEED	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
1	3.6	2.6	2.0	2.2	1.5	1.1	0.8	0.5	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	1.0
2	3.5	3.1	3.3	2.3	2.4	1.9	1.5	1.0	0.8	0.5	0.2	0.3	0.3	0.2	0.5	0.5	0.5	1.5
3	4.0	4.0	4.7	4.2	3.3	2.7	2.1	1.5	1.2	0.8	0.6	0.4	0.4	0.5	0.6	0.4	0.9	1.4
4	4.3	5.9	6.3	5.4	4.0	3.5	3.1	1.9	1.2	1.0	0.5	0.7	0.8	0.7	0.5	0.5	1.0	1.0
5	5.3	5.6	6.7	5.8	4.1	3.3	2.8	1.7	1.2	0.3	0.5	0.6	1.0	1.7	1.1	0.5	0.3	1.4
6	4.4	5.3	6.1	6.2	4.0	3.0	2.3	1.8	1.0	0.3	0.5	0.6	1.6	1.9	1.5	0.6	0.4	0.6
7	3.3	4.6	6.6	6.1	4.7	3.0	2.4	1.8	1.5	1.0	0.9	1.1	1.1	1.2	1.2	0.6	0.3	0.6
8	2.4	4.7	5.9	6.0	3.3	2.4	1.8	1.5	1.2	1.0	0.6	0.9	0.5	1.0	0.6	0.7	0.3	0.5
9	1.9	3.5	6.1	4.3	3.3	1.6	1.7	1.6	1.5	1.0	1.0	0.6	1.0	0.6	0.9	0.3	0.3	0.5
10	0.9	3.5	4.7	5.0	2.6	2.1	1.3	1.6	1.0	0.6	0.6	1.2	0.8	0.4	0.5	0.2	0.1	0.3
11	0.7	1.7	3.5	3.7	3.0	1.7	1.9	1.2	0.7	0.3	0.4	0.4	0.6	0.4	0.2	0.2	0.1	0.3
12	0.4	1.0	2.7	2.8	3.1	2.2	1.5	1.5	0.4	0.3	0.1	0.3	0.2	0.1	0.1	0.2	0.1	0.2
13	0.6	1.0	1.5	2.7	2.2	2.0	1.9	1.0	0.7	0.4	0.3	0.1	0.1	0.1	0.2	0.3	0.3	0.1
14	0.3	0.5	1.0	1.3	2.1	2.1	1.5	1.3	0.5	0.6	0.2	0.1	0.1	0.0	0.1	0.3	0.1	0.0
15	0.1	0.2	0.6	1.3	1.6	2.1	1.3	0.9	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
16	0.0	0.0	0.6	1.0	1.7	1.2	1.2	0.7	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.1	0.5	1.3	1.3	1.5	1.0	1.1	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.2	0.6	1.0	0.8	1.0	0.8	0.4	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.2	0.7	0.6	0.6	0.4	0.2	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.2	0.4	0.4	0.2	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.2	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.5	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.1	0.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

FREQUENCY DISTRIBUTI. . OF TURNER-CLASS, WIND SPEED AND DIRECTION

TURNER-CLASS 1

FREQUENCY OF CALMS 3.04 HOURS

WIND DIRECTION IN DEGREES

WIND SPEED	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.5	0.8	0.8	0.6	0.0	0.0	0.8	0.4	1.5
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

WIND DIRECTION IN DEGREES

WIND SPEED	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
1	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.0	0.0

TURNER-CLASS 2

FREQUENCY OF CALMS 21.27 HOURS

WIND DIRECTION IN DEGREES

WIND SPEED	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1	0.8	1.5	2.3	0.8	3.8	5.3	5.3	3.8	4.6	1.5	1.5	2.3	1.5	1.5	0.6	0.0	2.3	3.0
2	2.4	5.5	4.3	4.9	5.5	6.7	5.5	4.9	3.0	3.0	1.2	1.2	1.2	0.6	0.0	0.0	1.2	2.4
3	6.1	8.5	7.9	5.5	7.3	7.3	4.3	2.4	3.0	0.0	0.6	1.2	0.0	0.6	0.6	0.0	0.0	1.0
4	4.3	5.5	3.6	2.4	4.3	4.9	2.4	1.6	0.6	1.2	0.0	1.2	0.6	0.0	0.6	0.0	0.0	0.0
5	1.8	2.4	1.2	2.4	3.0	3.0	2.4	2.4	4.9	1.8	1.8	1.2	1.2	1.2	0.0	0.0	0.0	1.2
6	1.2	1.2	3.6	4.9	4.9	4.3	1.2	4.3	3.0	3.0	0.0	0.0	1.8	1.2	0.0	0.0	1.2	1.4
7	0.0	1.2	2.4	4.9	5.5	3.0	3.0	1.8	2.4	0.0	0.0	0.0	1.2	1.8	0.0	0.0	0.0	1.2
8	0.0	0.0	0.6	1.2	1.2	1.8	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.8	0.0	0.8

WIND DIRECTION IN DEGREES

WIND SPEED	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
1	2.3	0.8	2.3	0.0	0.0	1.5	2.3	3.0	1.5	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
2	2.4	3.6	3.0	5.5	2.4	1.8	4.3	3.6	3.0	0.6	0.0	0.0	0.6	0.0	0.6	0.0	0.6	0.0
3	3.6	4.3	9.7	7.3	6.7	4.9	3.0	4.3	2.4	1.2	0.0	0.0	0.6	0.0	0.0	0.0	1.0	3.0
4	1.8	4.3	3.6	6.7	5.5	4.3	3.0	0.6	1.2	0.0	0.0	0.0	0.6	1.8	1.2	1.2	1.2	2.4
5	1.8	1.2	4.3	6.1	7.3	6.1	3.6	1.2	0.0	0.0	0.0	0.0	1.2	1.8	1.8	0.0	1.2	1.2
6	1.8	3.6	5.5	9.1	7.3	6.7	3.0	0.6	0.6	0.0	0.0	0.0	1.2	1.2	1.2	0.0	0.0	0.0
7	1.8	2.4	6.7	7.9	8.5	5.5	4.3	1.8	0.6	0.0	0.6	1.2	1.2	1.2	0.0	0.0	0.0	0.0
8	0.0	1.2	1.8	3.0	1.8	2.4	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.8	0.8	1.5	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TURNER-CLASS 3

FREQUENCY OF CALMS 45.59 HOURS

WIND DIRECTION IN DEGREES

WIND SPEED	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1	0.8	2.3	4.6	3.0	2.3	4.6	3.8	5.3	7.6	8.4	6.8	5.3	3.0	1.5	0.8	3.8	4.0	5.9
2	1.8	4.3	4.3	5.5	4.9	8.5	6.1	4.9	6.1	5.5	4.3	3.0	1.8	0.6	2.4	1.5	4.3	3.6
3	3.6	3.6	5.5	6.1	9.7	10.9	8.5	6.1	4.9	3.0	3.0	2.4	0.6	1.8	2.4	2.4	2.4	3.0
4	2.4	3.0	7.3	6.7	10.9	10.3	5.5	4.3	4.3	1.5	1.8	2.4	1.2	0.6	2.4	1.2	0.6	2.4
5	1.2	6.1	6.1	10.9	8.5	9.1	2.4	4.3	2.4	1.3	1.2	2.4	1.8	1.8	0.6	0.0	1.2	0.6
6	1.2	2.4	6.7	4.9	9.7	6.7	3.6	1.8	3.0	0.0	0.6	2.4	1.8	1.2	1.2	0.6	0.6	1.2
7	1.8	1.2	4.9	9.1	9.1	10.3	4.9	2.4	2.4	0.6	0.6	0.6	0.6	1.2	0.0	0.0	0.6	0.0
8	1.8	3.6	7.9	10.3	13.4	9.1	4.9	4.3	3.6	4.3	0.6	1.2	0.6	0.0	0.6	0.6	0.0	1.5
9	1.8	3.6	5.5	10.3	6.7	5.5	3.0	1.8	6.1	3.0	3.0	0.6	0.6	0.6	0.6	0.6	1.2	1.2
10	1.2	0.6	3.0	2.4	3.0	0.6	0.0	1.2	1.8	2.4	0.0	0.6	0.0	0.0	0.0	0.5	0.0	0.6
11	0.0	0.6	0.0	1.2	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	1.2	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.6	0.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

WIND DIRECTION IN DEGREES

WIND SPEED	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
1	3.8	3.0	3.8	3.8	3.0	0.0	2.3	0.6	0.8	0.3	0.0	0.0	0.0	0.0	0.6	0.0	0.0	1.5
2	2.4	3.0	3.6	5.5	4.9	5.5	3.6	3.0	2.4	1.2	1.2	1.2	0.6	0.6	0.6	1.2	1.2	2.4
3	3.6	3.6	3.6	5.5	6.7	5.5	5.5	2.4	1.2	1.8	2.4	2.4	1.8	0.6	1.2	0.0	1.8	3.0
4	3.0	3.6	6.7	5.5	6.1	6.1	3.0	1.2	1.2	0.6	1.2	1.8	0.6	0.0	0.0	0.6	0.0	1.2
5	1.8	6.7	6.7	9.7	6.1	3.6	3.0	1.2	1.2	0.6	0.6	0.0	0.6	0.0	0.6	0.0	0.0	0.6
6	3.0	4.3	9.1	6.5	4.3	3.0	1.2	1.8	0.6	0.0	0.6	0.0	0.6	1.2	1.2	0.0	0.0	0.0
7	2.4	3.6	6.1	9.7	6.1	1.2	3.6	1.8	0.6	1.2	0.0	1.2	0.6	0.0	2.4	0.6	0.0	0.0
8	2.4	4.3	7.3	10.9	6.7	5.5	2.4	4.3	2.4	2.4	1.8	2.4	0.6	1.2	1.8	1.2	0.0	1.2
9	3.0	3.0	4.9	6.1	4.3	1.8	5.5	4.3	4.9	4.3	4.3	2.4	1.8	1.2	1.2	0.0	0.0	1.2
10	1.2	3.6	3.6	3.6	1.8	3.0	3.6	4.9	2.4	3.0	1.2	3.0	1.2	1.2	1.2	0.0	0.0	0.0
11	0.6	1.2	3.0	2.4	1.2	2.4	3.6	3.0	1.2	0.6	1.2	0.6	0.0	1.2	0.0	0.0	0.0	0.0
12	0.0	0.0	0.6	1.2	1.2	0.0	1.2	1.2	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.6	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	1.2	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TURNER-CLASS 4

FREQUENCY OF CALMS 72.94 HOURS

WIND DIRECTION IN DEGREES

WIND SPEED	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1	3.8	6.8	6.1	8.4	9.1	9.1	5.3	6.8	7.6	3.8	3.8	0.6	0.6	1.5	1.5	4.5	5.3	5.3
2	5.5	4.3	6.7	8.5	7.9	7.3	5.5	6.1	7.3	8.5	4.3	6.7	2.4	1.6	3.6	3.0	4.9	5.7
3	5.5	9.7	10.3	10.3	12.3	13.4	10.3	7.9	9.7	7.3	7.9	5.5	5.5	2.4	1.0	3.0	2.4	3.0
4	12.2	14.0	17.6	20.7	20.1	26.1	19.4	16.4	15.2	9.7	5.5	6.1	2.4	1.6	2.4	2.4	1.2	8.5
5	6.1	12.2	15.2	25.5	28.6	25.5	17.0	17.6	15.2	12.2	4.9	3.6	1.2	0.6	1.6	3.0	4.9	6.7
6	5.5	10.9	15.8	20.7	23.7	15.2	9.1	10.9	14.0	7.9	3.6	1.2	1.2	0.0	1.6	4.3	4.3	10.3
7	6.7	15.3	17.6	17.0	14.6	9.1	4.3	6.5	6.1	5.5	4.3	1.8	0.6	0.6	0.0	1.2	3.6	6.5
8	7.9	16.4	15.2	15.8	6.1	4.9	4.3	3.6	3.6	5.5	3.0	1.8	0.6	0.0	0.0	0.0	0.6	2.1
9	7.3	20.7	22.5	15.2	9.1	4.3	3.0	4.3	3.0	1.8	3.0	1.2	0.0	0.0	0.0	0.0	0.6	2.4
10	11.5	23.1	24.3	19.4	7.3	3.6	3.0	2.4	1.2	1.8	1.8	1.8	1.2	0.0	0.0	0.0	0.6	3.0
11	9.1	22.5	24.9	17.0	5.5	3.6	1.2	1.2	0.6	0.6	1.2	2.4	0.6	0.0	0.0	0.0	0.0	1.8
12	7.3	21.3	25.5	17.0	10.3	1.6	2.4	0.6	0.0	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0	1.8
13	6.1	14.6	18.8	17.6	6.7	4.3	1.2	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
14	1.8	8.5	10.3	7.9	5.5	0.6	0.6	0.6	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
15	3.0	7.3	8.5	7.9	3.0	0.6	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1.6	6.7	9.1	7.9	3.6	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.6	6.1	6.7	8.5	2.4	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1.2	3.0	5.5	3.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.6	1.8	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

WIND DIRECTION ( ) DEGREES

WIND SPEED	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
1	6.1	2.3	3.8	3.0	3.8	2.3	0.8	0.0	0.0	0.8	0.8	1.5	0.8	0.8	0.8	2.3	2.3	4.9
2	5.5	6.1	4.9	4.9	4.9	4.3	2.4	1.2	0.6	1.2	0.6	0.0	1.2	0.0	2.4	1.8	3.0	3.0
3	11.5	9.1	9.1	9.1	6.7	6.7	6.7	4.3	3.6	2.4	1.2	0.6	0.6	2.4	1.2	4.3	1.2	5.5
4	15.2	19.4	19.4	16.4	12.2	10.3	12.8	10.3	5.5	3.0	0.6	0.6	3.0	1.2	4.3	1.2	4.3	6.7
5	22.5	20.1	24.3	20.1	14.0	9.7	12.8	10.3	4.3	1.2	1.2	3.0	4.3	6.1	3.6	3.0	0.0	4.3
6	16.4	20.1	20.7	23.1	12.8	10.3	10.9	9.1	4.9	3.0	2.4	4.9	7.3	7.9	6.7	3.6	1.2	1.2
7	22.5	28.6	38.9	31.0	23.1	16.4	11.5	11.5	9.7	7.3	6.1	6.7	7.9	7.3	7.3	4.3	3.0	3.6
8	17.0	32.8	37.1	35.9	18.2	12.2	11.5	8.5	8.5	5.5	3.6	4.9	3.6	6.1	3.0	4.3	2.4	2.4
9	12.8	23.7	43.2	28.6	23.1	11.5	9.1	9.7	7.9	4.3	4.3	4.9	6.7	3.6	5.5	2.4	2.4	3.6
10	6.7	24.3	35.4	37.7	20.1	15.2	7.9	9.1	6.7	4.3	3.6	7.3	5.5	6.1	3.0	1.8	1.2	1.8
11	5.5	15.2	27.4	30.4	24.9	12.8	12.8	7.9	4.9	1.8	2.4	3.0	4.3	2.4	1.8	1.8	0.6	2.4
12	3.6	7.9	23.1	23.7	24.1	13.3	12.2	12.2	3.6	3.0	1.2	1.8	1.8	0.6	1.2	1.8	1.2	1.8
13	4.9	8.5	12.8	23.1	19.4	17.6	16.4	8.5	6.1	3.6	3.0	0.6	1.2	0.6	1.8	3.0	2.4	1.2
14	3.0	4.3	9.1	11.5	17.6	18.2	13.4	11.5	4.3	4.9	1.8	0.6	0.6	0.0	0.6	2.4	1.2	0.0
15	1.2	1.8	4.9	10.9	13.4	17.0	11.5	7.9	3.6	2.4	1.2	0.0	0.0	0.0	0.0	0.6	0.6	0.0
16	0.0	0.0	4.9	9.1	14.6	10.3	10.3	6.1	3.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	1.2	4.3	11.5	10.3	12.8	8.5	9.7	4.9	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	1.8	4.3	7.3	5.5	8.5	7.3	3.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	1.8	4.9	4.9	5.5	3.6	1.8	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	1.8	3.6	3.6	1.8	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.6	3.0	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	2.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	1.8	1.8	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	4.3	1.8	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.6	0.6	3.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.6	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	1.2	1.8	1.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TURNER-CLASS 5

FREQUENCY OF CALMS 0.0 HOURS

WIND DIRECTION IN DEGREES

WIND SPEED	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
4	7.6	7.6	9.9	9.9	16.7	12.2	7.6	4.6	3.8	3.0	1.5	0.8	0.0	1.5	1.5	2.3	2.3	6.1
5	3.6	6.7	5.5	9.7	14.6	12.2	6.1	2.4	1.8	1.8	0.6	0.0	0.0	0.0	1.2	0.6	3.0	7.9
6	3.6	4.9	5.5	6.1	10.3	9.1	5.5	0.6	1.2	0.6	0.6	0.0	0.0	0.0	0.0	0.0	1.8	5.5
7	2.4	5.5	5.5	5.5	6.1	5.5	4.3	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
8	2.4	4.3	6.7	4.9	4.9	1.8	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	1.2	1.8	3.0	6.7	3.6	2.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	1.5	3.0	4.6	5.3	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

WIND DIRECTION IN DEGREES

WIND SPEED	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
4	10.6	13.7	13.7	10.6	7.6	6.8	5.3	2.3	0.8	3.8	2.3	2.3	2.3	1.5	0.8	0.0	3.0	3.0
5	12.2	14.0	14.6	9.1	5.5	6.7	3.0	0.6	3.6	1.2	2.4	1.8	1.2	3.0	1.2	0.6	0.6	3.6
6	9.7	9.7	10.9	7.3	6.1	4.3	3.6	3.6	2.4	3.6	0.6	0.6	2.4	2.4	1.8	0.6	1.2	1.2
7	2.4	5.5	6.1	4.9	3.6	3.0	1.2	0.6	2.4	0.6	0.6	0.6	0.0	1.2	1.2	0.0	0.0	1.2
8	1.2	3.0	5.5	3.0	2.4	1.2	0.0	0.0	0.0	0.6	0.0	0.0	0.0	1.2	0.0	0.6	0.0	0.0
9	0.6	3.0	4.3	1.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6	1.2	0.0	0.0	0.0
10	0.0	2.3	3.8	2.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0

FREQUENCY OF CALMS 124.60 HOURS

WIND DIRECTION IN DEGREES

WIND SPEED	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1	6.1	6.8	4.6	9.1	12.9	11.4	10.6	5.3	5.3	5.3	5.3	5.3	5.3	3.8	4.6	2.3	6.1	9.9
2	6.1	5.5	10.9	7.9	10.9	12.2	6.7	6.7	4.3	4.9	5.5	7.3	3.6	4.9	3.5	3.0	4.3	10.3
3	3.6	10.3	11.5	12.2	12.6	15.3	13.4	6.1	4.9	5.5	6.1	6.7	4.3	1.2	3.0	1.8	3.0	6.7
4	5.5	6.5	17.6	14.0	24.9	26.1	20.7	8.5	5.5	3.0	3.6	4.3	1.2	0.0	1.2	1.2	1.2	4.3
5	4.3	12.2	14.0	23.1	23.7	26.1	15.2	7.3	3.6	3.6	1.8	1.8	0.0	0.0	0.0	0.6	1.2	3.6
6	3.8	6.1	16.0	17.5	22.0	14.4	7.6	2.3	2.3	1.5	1.5	0.8	0.0	0.0	0.0	0.0	0.0	4.6

WIND DIRECTION IN DEGREES

WIND SPEED	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
1	10.6	9.1	3.8	6.1	3.0	2.3	0.8	0.0	0.0	0.0	0.8	0.8	0.8	0.0	0.0	0.0	1.5	6.1
2	11.5	7.9	10.9	6.1	5.5	3.6	1.2	0.6	0.6	0.6	0.0	1.2	0.0	0.0	0.0	1.2	1.2	3.6
3	10.3	13.4	14.0	11.5	6.7	4.9	2.4	2.4	2.4	1.2	1.2	0.6	0.6	0.6	1.2	1.2	1.8	2.4
4	7.3	10.9	11.5	8.5	3.6	3.0	3.0	1.8	1.8	1.2	0.0	0.6	0.6	1.8	0.6	1.2	0.6	1.2
5	8.5	8.5	8.5	5.5	3.0	3.0	1.8	1.2	0.6	0.0	0.0	0.6	1.2	3.0	1.8	0.6	0.6	2.4
6	7.6	9.1	6.8	6.1	4.6	2.3	1.5	0.8	0.0	0.0	0.8	0.8	2.3	3.0	2.3	0.8	0.8	0.0

TURNER-CLASS 7

FREQUENCY OF CALMS 136.75 HOURS

WIND DIRECTION IN DEGREES

WIND SPEED	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1	3.0	3.8	4.6	9.9	15.2	16.0	9.9	4.6	4.6	6.1	3.0	3.8	3.8	3.0	1.5	2.3	3.0	4.6
2	4.3	4.9	10.9	18.8	27.4	27.4	14.6	9.7	10.9	6.7	4.3	2.4	3.0	1.2	1.8	2.4	3.0	7.3
3	3.0	6.8	14.4	31.2	39.5	36.5	24.3	15.2	13.7	9.9	2.3	1.5	1.5	0.8	0.0	1.5	2.3	1.5

WIND DIRECTION IN DEGREES

WIND SPEED	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
1	8.4	6.8	3.8	6.1	3.0	3.8	0.8	0.8	0.8	0.0	0.0	0.8	0.8	0.8	0.8	3.0	6.1	1.5
2	7.9	6.7	6.1	3.0	3.0	1.2	1.2	0.6	0.6	0.6	0.0	0.0	0.6	0.6	0.6	0.6	0.0	3.6
3	6.1	4.6	4.6	3.8	2.3	1.5	0.8	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.8	0.0	1.5	2.3

The stability classes by KLUG/MANIER

The stability classes by KLUG are determined from synoptic observations of wind velocity, cloud cover and cloud height as well as daytime and season. There are the classes I to V which are connected to the stratification by:

class	stratification
I	very stable
II	stable
III_1	indifferent - stable
III_2	indifferent - instable
IV	instable
V	very instable

The stability class is determined from cloud cover and wind velocity by the following scheme:

wind velocity at 10 m height	night time		day time		
kts	0/8 - 6/8	7/8 - 8/8	0/8 - 2/8	3/8 - 5/8	6/8 - 3/8
2	I	II	IV	IV	IV
3 - 4	I	II	IV	IV	III_2
5 - 6	II	III_1	IV	IV	III_2
7 - 8	III_1	III_1	IV	III_2	III_2
$\geqslant$ 9	III_1	III_1	III_2	III_1	III_1

The stability classes will be modified in the following way:

a) During the months June and July between 11.00 and 15.00 MEZ and during the months August and May between 12.00 and 14.00 MEZ the next higher stability class will be taken,

if the wind velocity is less than 9 kts and the total coverage less than 5/8; by this operation the stability class V becomes possible.

b) During the months December, January and February the stability class IV of the above given scheme should be replaced by the stability class III_2.

c) For sources, not existing near the ground, but with a source height less than 100 m, the stability class of the nighttime will be taken still for an hour after sunrise. For source-heights more / equal 100 m the stability class of the nighttime will be taken still for two hours after sunrise. Moreover by computing the concentration coming from source heights more than 150 m, one has to take the stability class I instead of stability class II.

d) In the time of two hours before sunset the following regulation will be suggested:

I. If the stability class of the day- and nighttime differs by a class (e. g. on day III_2, at night III_1) then the stability class of the daytime has to be taken.

II. If the stability classes of the day and night are differing by more than two ore three classes, the class of the daytime is reduced by one class.

III. At a difference of 4 classes, the daytime value is reduced by two classes.

e) If the coverage consists exclusively of high clouds (Cirrus), the total cloud coverage is reduced by 3/8.

MANIER's additional comment:

A. For 1 to 3 hours after sunrise and 2 hours before to 1 hour after sunset the stability class for day as well as for night has to be determined. The following table contains in all possible combinations of "day" and "night" classes the stability class which has to be taken.

$class_{night}$ - $class_{day}$	SR+1 - SR+2	SR+2 - SR+3	SS-2 - SS-1	SS-1 - SS	SS - SS+1
I - IV	I (II)[1]	II	II	II (I)[2]	I (II)[1]
I - III_2	II	II	III_1	III_1	I (II)[1]
II - IV	II	III_1	III_1	II	II
II - III_2	III_1	III_1	III_1	III_1	II
III_1 - IV	III_1	III_2	III_2	III_1	III_1
III_1 - III_2	III_1	III_1	III_2	III_2	III_1
III_1 - III_1	III_1	III_1	III_1	III_1	III_1

SR = sunrise

SS = sunset

(1) During the months March to November and at a wind velocity more than 2 kts the stability class II should be taken.

(2) During the months January, February and December at a wind velocity less / equal 2 kts and a cloud coverage less / equal 6/8 the class I has to be taken.

B. During the months June to August between 10.00 and 16.00 MEZ and at a cloud coverage of N = 6/8 the stability class is increased by one unit. If the coverage is N = 7/8 and the wind velocity less than 5 kts, than the stability class is increased by one unit too. For the same months between 12.00 and 15.00 MEZ and a cloud coverage N = 5/8 the stability

class is increased once more by one unit. If the stability class is V, than there should be no increase.

During the months May and September between 11.00 and 15.00 MEZ and a cloud coverage N = 6/8 the stability is increased by one unit.

Comment on the listed statistic of stability classes (Printed table)

The tables are constructed in the following way:

Table 1 contains the wind distribution with wind-velocity in steps of 1 kt on the abszissa and wind direction in steps of 10° on the ordinate. WS means calm, UW variable winds. The frequency is given as 1/100 percent taking the number of evaluated (FF, DD)-values for 100 percent.

The following table shows the frequency distribution of the stability classes I - V by KLUG/MANIER depending on wind velocity and wind direction; the number of evaluated (FF, DD)-values is taken for 100 % too.

The table KLUG-class N = 9 presents cases, for which the coverage was not defined and no determination of a stability class had been possible.

Small variations between the number of evaluated (FF, DD)-values of the wind frequency distribution and the sum of evaluated (FF, DD)-values in the stability classes may arise because of the applied smoothing method, which eventually eliminates subjective errors of evaluation.

Evaluation of degree-days for the Test-City

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
Z	1	19	31	30	31	31	29	31	29	20	10	3
t_{am}	14.9	12.5	9.8	4.8	4.4	-0.1	3.9	7.5	9.3	11.3	13.4	13.8
G	5	143	316	456	484	623	467	388	310	174	66	19

The uninterrupted heating period lasts from 26.09.1971 till 29.04.1972 with a duration of 217 days.

The number of degree days per month is evaluated in the following way:

$$G = Z\ (t_i - t_{am})$$

with

G = number of degree days

Z = number of days per month, where the temperature has beyond + 15 °C (heating days)

t_i = + 20° (desired constant roomtemperature)

t_{am} = mean value of temperature, formed by the average daily temperature of all heating days in a month.

Period 8/71 - 7/72

Source height < 100 m

Smoothed frequency distribution

of wind velocity (kts)/wind direction (10°)

(KLUG /MANIER)

WS	0,1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
	478	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	19	22	25	34	19	16	12	14	12	14	10	8	7	2	3	2	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*
2	20	31	46	42	44	27	28	27	29	28	26	24	17	10	8	8	7	3	2	1	*	*	*	*	*	*	*	*	*	*	*	*
3	20	49	56	66	47	50	36	34	35	33	29	30	22	12	10	10	8	6	1	*	*	*	*	*	*	*	*	*	*	*	*	*
4	24	60	71	65	80	57	46	36	36	29	23	20	21	9	9	9	10	4	1	*	*	*	*	*	*	*	*	*	*	*	*	*
5	36	69	87	101	89	75	44	29	22	16	7	12	8	6	3	4	3	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	51	75	89	98	87	53	34	20	14	6	4	2	5	1	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	48	45	65	65	49	30	20	14	8	3	1	3	1	1	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	32	39	40	43	39	22	17	10	7	4	1	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	34	36	40	37	31	26	12	8	10	3	1	*	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	36	34	28	23	24	14	8	11	5	5	1	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	26	23	23	14	12	7	6	4	7	2	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	22	27	20	16	10	5	3	3	2	3	3	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	20	14	14	7	5	5	3	2	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	17	10	8	4	4	3	4	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	14	14	10	9	4	4	1	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	9	16	10	8	5	5	1	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	15	19	14	5	12	9	5	1	2	1	1	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	36	33	19	25	23	25	12	9	4	4	2	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	43	34	42	41	53	42	35	23	18	9	7	4	5	3	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	27	37	43	58	57	50	48	46	34	33	18	10	10	5	2	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	20	34	53	62	68	59	66	59	59	46	35	27	14	10	5	5	5	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	20	34	45	57	59	61	65	60	44	49	38	28	27	13	13	10	13	6	2	2	1	*	2	*	1	*	*	*	*	*	*	*
23	15	28	38	42	45	40	48	34	33	27	29	31	22	20	16	17	13	10	7	4	3	3	2	5	1	1	1	*	*	*	*	*
24	10	24	31	37	35	30	30	24	16	20	17	21	20	20	20	12	14	8	5	4	1	1	4	2	3	1	2	1	*	*	*	*
25	5	16	23	31	29	23	24	18	16	13	18	15	18	15	13	12	10	10	6	2	1	*	*	3	1	1	2	1	*	*	*	*
26	5	13	16	19	16	18	18	14	16	16	12	15	10	13	9	7	11	8	4	1	*	*	*	*	1	*	1	*	*	*	*	*
27	2	10	13	12	12	10	15	12	14	10	7	4	7	5	4	4	5	4	2	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	6	8	9	3	8	10	10	10	8	3	3	4	5	3	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	2	2	7	4	5	5	9	6	10	5	4	1	3	2	1	*	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*
30	3	3	5	6	6	8	12	9	8	12	4	3	1	1	*	*	*	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*
31	5	3	4	8	10	15	11	5	10	8	5	2	1	1	*	*	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*
32	3	3	5	7	16	18	13	10	6	9	4	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	6	5	8	11	15	13	6	9	5	2	1	2	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	2	6	8	5	6	6	5	7	3	2	2	2	3	3	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	2	9	9	10	3	4	3	3	3	1	1	1	3	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	7	14	20	18	14	4	5	5	5	3	3	2	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	31	85	78	20	20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

DD

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 2932 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source height < 100 m

Smoothed frequency distribution of wind velocity (kts)/wind direction (10^0) for the KLUG-stability class I.

(MANIER)

WS \ DD	0,1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
	1562	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
1	41	51	37	67	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
2	51	62	95	77	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
3	31	154	140	149	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
4	41	211	247	170	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
5	82	267	288	241	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
6	144	283	304	283	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
7	123	170	247	195	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
8	51	139	119	134	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
9	62	103	107	77	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
10	51	72	74	36	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
11	21	46	25	31	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
12	41	36	33	21	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
13	62	26	21	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
14	62	15	8	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
15	41	21	16	21	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
16	10	31	16	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
17	10	36	21	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
18	51	87	33	36	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
19	103	98	82	51	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
20	72	103	86	103	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
21	51	98	115	123	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
22	51	57	78	87	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
23	41	41	29	26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
24	41	21	29	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
25	21	21	12	21	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
26	10	15	21	21	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
27	*	15	25	21	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
28	*	10	8	21	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
29	*	*	8	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
30	*	*	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
31	10	*	*	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
32	10	5	8	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
33	*	5	8	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
34	*	10	4	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
35	*	15	12	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
36	10	36	33	36	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
UW	21	41	62	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 487 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 3/71 - 7/72

Source height < 100 m

Smoothed frequency distribution of wind velocity (kts)/wind direction (10^0) for the KLUG-stability class II.

(MANIER)

(NACH MANIER)

WS	0,1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
	810	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
1	63	36	25	36	32	23	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
2	54	36	65	58	83	50	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
3	54	68	76	119	104	113	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
4	72	72	101	137	169	117	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
5	108	81	151	191	187	158	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
6	126	113	133	187	166	104	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
7	99	63	83	112	83	50	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
8	81	45	65	50	54	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
9	72	68	58	61	29	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
10	63	59	50	32	22	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
11	63	50	54	22	14	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
12	45	59	43	29	7	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
13	9	23	29	7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
14	*	27	18	7	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
15	18	32	25	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
16	27	32	18	14	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
17	27	32	32	11	25	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
18	63	54	40	68	40	45	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
19	72	50	86	76	104	77	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
20	27	59	79	97	83	90	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
21	27	59	86	72	65	72	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
22	36	59	90	83	65	63	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
23	27	50	79	86	54	41	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
24	18	36	58	79	40	23	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
25	*	9	43	50	36	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
26	*	14	7	29	11	23	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
27	*	5	11	4	14	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
28	*	9	4	14	7	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
29	9	*	11	7	11	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
30	18	5	11	11	11	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
31	18	5	7	11	11	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
32	9	*	11	14	22	32	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
33	*	5	7	7	18	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
34	9	5	11	4	7	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
35	9	9	11	14	7	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
36	27	14	22	11	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
UW	*	36	90	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	

DD

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 555 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 6/71 - 7/72

Source height < 100 m

Smoothed frequency distribution of wind velocity (kts)/wind direction (10^0) for the KLUG-stability class III.1 (MANIER)

(NACH MANIER)

WS	0,1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
	43	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	*	6	17	28	19	23	14	21	21	29	24	19	17	5	9	5	2	3	2	*	*	*	*	*	*	*	*	*	*	*	*	*
2	4	11	16	29	31	28	40	42	61	71	64	59	42	24	21	17	17	9	5	2	*	*	*	*	*	*	*	*	*	*	*	*
3	4	6	17	23	35	42	47	52	73	80	71	66	50	29	21	23	17	14	3	*	*	*	*	*	*	*	*	*	*	*	*	*
4	*	9	9	23	61	61	55	59	69	66	48	40	38	17	19	17	21	9	2	*	*	*	*	*	*	*	*	*	*	*	*	*
5	*	4	10	45	81	74	50	33	40	35	16	19	10	9	5	7	7	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	4	4	12	36	71	52	35	14	21	12	10	5	5	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	9	4	16	28	43	35	21	17	9	7	3	5	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	9	11	16	26	40	23	26	5	7	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	13	9	14	24	29	33	7	7	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	22	15	10	14	29	14	9	5	3	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	17	11	12	10	10	12	2	2	5	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	4	15	9	10	12	5	3	2	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	9	6	7	5	3	3	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	9	4	3	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	*	6	5	3	3	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	*	4	5	5	5	9	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	13	4	3	2	12	14	7	*	3	2	2	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	26	9	10	9	26	33	21	14	9	10	5	5	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	17	15	17	29	61	55	57	45	38	23	16	10	14	9	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	13	6	14	36	66	69	74	87	76	76	42	21	23	10	5	*	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	13	2	10	40	80	66	97	102	128	106	78	59	31	23	10	14	12	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	9	6	9	33	54	61	76	94	88	113	85	66	64	29	29	24	29	12	3	5	2	*	5	*	2	*	*	*	*	*	*	*
23	4	9	14	19	31	31	47	45	66	57	66	71	55	47	35	35	26	16	12	9	9	7	5	10	2	2	3	*	*	*	*	*
24	*	15	14	17	23	24	35	28	35	47	35	52	45	47	38	24	26	12	10	10	3	2	9	3	7	3	5	3	*	*	*	*
25	*	9	12	17	17	23	16	21	31	28	38	33	42	29	24	17	17	16	10	3	2	*	*	5	2	3	5	2	*	*	*	*
26	*	4	9	9	10	14	12	14	29	31	24	29	17	23	12	12	23	17	9	2	*	*	*	*	2	*	2	*	*	*	*	*
27	*	4	5	9	5	7	17	17	29	24	14	10	12	9	7	9	14	10	5	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	4	7	5	2	9	14	19	19	19	7	9	9	12	5	2	3	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	2	3	2	*	3	12	7	21	14	10	3	9	3	3	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	2	3	2	5	5	9	12	16	28	10	7	2	2	*	*	*	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
31	*	2	3	5	5	10	7	2	23	16	14	5	3	2	*	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*
32	*	2	3	2	14	12	10	14	12	19	7	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	6	3	7	7	12	10	5	16	9	5	3	3	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	4	7	2	5	3	3	5	3	3	5	3	7	5	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	9	5	10	*	2	2	*	3	3	2	3	5	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	*	9	16	19	14	3	7	3	5	5	5	5	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	*	17	17	*	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD																																

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 1155 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source height < 100 m

Smoothed frequency distribution of wind velocity (kts)/wind direction (10^0) for the KLUG-stability class III 2 (MANIER)

(NACH MANIER)

	0,1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G3C	FF
WS	77	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	*	6	15	20	10	10	36	36	20	20	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	13	15	26	41	31	56	61	41	*	5	5	5	*	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	*	6	15	51	36	56	66	72	36	15	5	31	15	5	10	10	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4	*	13	15	31	82	51	77	66	56	20	26	31	46	15	10	15	10	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*
5	13	19	20	56	61	82	66	72	41	20	5	36	26	20	10	10	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	13	13	20	36	51	51	56	46	31	10	*	*	20	5	5	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	26	6	10	15	20	26	20	20	15	5	*	5	5	5	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	26	19	5	26	36	36	26	20	31	26	5	*	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	*	13	31	26	46	41	31	20	46	26	10	*	5	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	*	26	5	26	20	31	26	46	31	26	5	*	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	*	6	26	5	15	5	31	20	31	10	10	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	*	19	15	20	5	5	10	15	10	15	15	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	*	6	15	5	5	5	5	5	5	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	*	*	10	*	5	*	5	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	*	6	5	10	5	10	*	5	10	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	*	6	5	*	10	10	5	5	10	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	*	6	5	*	5	10	10	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	*	6	*	5	15	20	20	20	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	*	*	5	31	31	41	56	36	20	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	13	*	15	20	51	41	87	77	31	26	15	10	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	13	6	20	51	46	92	128	107	61	31	36	26	15	10	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	*	13	31	41	82	102	148	107	41	31	31	15	10	10	10	5	10	10	5	*	*	*	*	*	*	*	*	*	*	*	*	*
23	*	13	26	36	56	92	133	82	41	26	26	20	*	15	15	26	20	26	15	5	*	*	*	5	*	*	*	*	*	*	*	*
24	*	19	36	26	41	56	77	61	10	15	26	5	15	15	41	15	31	20	10	*	*	*	5	5	5	*	*	*	*	*	*	*
25	13	19	31	46	61	56	87	56	31	15	26	15	15	26	26	36	20	26	15	5	*	*	*	5	*	*	*	*	*	*	*	*
26	13	*	10	36	46	56	77	61	31	26	20	26	20	31	31	15	15	10	5	*	*	*	*	*	*	*	*	*	*	*	*	*
27	*	*	5	5	26	20	41	36	20	5	10	*	15	10	10	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	*	*	5	*	10	26	10	10	5	*	*	5	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	*	5	*	10	10	20	10	10	*	*	*	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	6	5	10	15	31	31	20	10	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
31	*	*	5	10	31	56	51	26	10	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
32	*	*	*	*	26	56	46	20	10	10	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	*	5	5	15	41	41	15	10	10	*	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	6	10	10	10	26	26	26	10	5	*	5	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	6	10	5	*	15	20	20	15	*	*	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	*	13	10	10	10	10	20	20	26	5	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	*	26	51	26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

DD

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 392 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source height < 100 m

Smoothed frequency distribution of wind velocity (kts)/wind direction (10^0) for the KLUG-stability class IV (MANIER)

(NACH MANIER)

	0.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
WS	163	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	*	41	87	65	11	33	33	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	81	130	76	87	54	43	54	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	27	54	98	98	65	87	54	68	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4	27	41	54	54	98	54	76	68	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5	*	27	33	87	87	98	98	95	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	*	14	65	65	108	98	119	108	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	*	27	11	54	65	54	87	54	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	*	14	11	33	76	54	43	68	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	*	14	11	22	76	43	43	41	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	27	14	*	22	43	22	11	27	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	27	*	*	*	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	*	*	*	*	*	11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	27	*	*	*	11	11	11	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	54	*	*	*	11	11	11	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	27	27	*	11	11	11	*	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	*	27	22	11	11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	27	54	11	11	11	11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	54	27	22	33	11	11	11	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	27	27	43	54	22	22	22	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	*	68	65	87	76	43	22	27	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	*	68	98	87	98	87	76	41	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	27	81	54	76	98	119	98	122	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
23	27	41	43	43	76	33	108	81	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
24	*	41	43	43	65	65	54	95	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
25	*	68	43	54	43	22	54	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26	27	54	65	22	54	11	11	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
27	27	41	33	54	22	22	11	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	*	33	11	22	*	11	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	14	22	22	11	*	11	27	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	*	11	11	*	11	22	27	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
31	*	*	*	*	*	*	11	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
32	*	*	*	11	*	*	11	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	14	11	11	11	11	22	27	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	14	11	22	*	*	11	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	14	22	11	11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	*	14	43	22	*	11	*	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	108	434	217	54	163	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

DD

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 184 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 6/71 - 7/72

< 100 m

Source height

Smothed frequency distribution of

wind velocity (kts)/wind direction

(10°) for the KLUG-stability class V

(KANIER)

(NACH MANIER)

WS	0.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
1	*	22	*	18	35	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	44	18	18	18	35	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	*	44	35	18	53	88	70	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4	*	44	18	18	53	123	88	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5	*	44	35	53	70	105	105	44	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	*	22	35	35	53	88	70	88	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	*	*	*	18	18	18	53	44	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	*	*	*	*	18	70	18	44	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	44	*	18	18	53	70	70	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	44	22	35	35	18	53	*	44	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	*	*	18	18	35	*	18	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	88	*	*	35	53	35	18	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	88	*	*	18	53	70	35	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	*	*	*	*	53	53	70	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	*	*	*	*	*	35	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	*	22	*	*	*	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	44	22	18	*	18	35	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	44	22	*	*	18	53	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	44	*	*	*	35	35	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	44	*	*	35	35	35	18	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	*	*	35	53	53	88	70	44	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	*	44	35	53	123	123	105	66	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
23	*	22	35	70	140	140	70	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
24	*	22	18	88	140	123	53	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
25	*	22	*	18	70	53	35	44	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26	*	44	35	*	*	18	35	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
27	*	66	35	18	18	18	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	22	18	*	*	18	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	*	*	*	*	18	18	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	*	*	18	*	*	35	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
31	*	22	18	18	35	18	18	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
32	*	22	18	35	53	18	18	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	22	*	35	53	35	18	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	*	*	*	35	*	*	22	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	*	*	*	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	*	*	*	18	35	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	525	876	613	350	175	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

DD

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 114 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source height < 100 m

Smoothed frequency distribution of wind velocity (kt)/wind direction (10^0) for the KLUG-stability class N=9 (MANIER)

(NACH MANIER)

	0.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
WS	1457	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	52	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	104	156	125	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4	104	104	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5	*	104	42	*	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	*	104	42	*	83	42	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	104	52	*	42	42	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	104	*	*	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	208	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	208	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	104	52	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	104	104	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	*	104	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	*	52	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	104	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	104	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	*	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	*	104	42	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	104	52	125	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	104	104	125	125	42	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	*	52	166	125	166	42	42	83	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	*	156	166	291	166	125	125	42	83	42	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
23	*	208	291	250	291	83	42	83	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
24	*	104	125	208	125	42	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
25	*	*	83	83	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26	*	52	42	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
27	*	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
31	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
32	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD																																

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 48 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source height ≥ 100 m

Smoothed frequency distribution

of wind velocity (kts)/wind direction (10^0)

KLUG /MANIER)

	0,1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	F
WS	478	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	19	22	25	34	19	16	12	14	12	14	10	8	7	2	3	2	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*
2	20	31	46	42	44	27	28	27	29	28	26	24	17	10	8	8	7	3	2	1	*	*	*	*	*	*	*	*	*	*	*	*
3	20	49	56	66	47	50	36	34	35	33	29	30	22	12	10	10	8	6	1	*	*	*	*	*	*	*	*	*	*	*	*	*
4	24	60	71	65	80	57	46	36	36	29	23	20	21	9	9	9	10	4	1	*	*	*	*	*	*	*	*	*	*	*	*	*
5	36	69	87	101	89	75	44	29	22	16	7	12	8	6	3	4	3	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	51	75	89	98	87	53	34	20	14	6	4	2	5	1	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	48	45	65	65	49	30	20	14	8	3	1	3	1	1	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	32	39	40	43	39	22	17	10	7	4	1	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	34	36	40	37	31	26	12	8	10	3	1	*	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	36	34	28	23	24	14	8	11	5	5	1	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	26	23	23	14	12	7	6	4	7	2	1	1	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	22	27	20	16	10	5	3	3	2	3	3	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	20	14	14	7	5	5	3	2	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	17	10	8	4	4	3	4	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	14	14	10	9	4	4	1	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	9	16	10	8	5	5	1	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	15	19	14	5	12	9	5	1	2	1	1	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	36	33	19	25	23	25	12	9	4	4	2	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	43	34	42	41	53	42	35	23	18	9	7	4	5	3	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	27	37	43	58	57	50	48	46	34	33	18	10	10	5	2	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	20	34	53	62	68	59	66	59	59	46	35	27	14	10	5	5	5	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	20	34	45	57	59	61	65	60	44	49	38	28	27	13	13	10	13	6	2	2	1	*	2	*	1	*	*	*	*	*	*	*
23	15	28	38	42	45	40	48	34	33	27	29	31	22	20	16	17	13	10	7	4	3	3	2	5	1	1	1	*	*	*	*	*
24	10	24	31	37	35	30	30	24	16	20	17	21	20	20	20	12	14	8	5	4	1	1	4	2	3	1	2	1	*	*	*	*
25	5	16	23	31	29	23	24	18	16	13	18	15	18	15	13	12	10	10	6	2	1	*	*	3	1	1	2	1	*	*	*	*
26	5	13	16	19	16	18	18	14	16	16	12	15	10	13	9	7	11	8	4	1	*	*	*	*	1	*	1	*	*	*	*	*
27	2	10	13	12	12	10	15	12	14	10	7	4	7	5	4	4	5	4	2	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	6	8	9	3	8	10	10	10	8	3	3	4	5	3	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	2	2	7	4	5	5	9	6	10	5	4	1	3	2	1	*	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*
30	3	3	5	6	6	8	12	9	8	12	4	3	1	1	*	*	*	1	1	1	*	*	*	*	*	*	*	*	*	*	*	*
31	5	3	4	8	10	15	11	5	10	8	5	2	1	1	*	*	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*
32	3	3	5	7	16	18	13	10	6	9	4	1	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	6	5	8	11	15	13	6	9	5	2	1	2	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	2	6	8	5	6	6	5	7	3	2	2	2	3	3	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	2	9	9	10	3	4	3	3	3	1	1	1	3	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	7	14	20	18	14	4	5	5	5	3	3	2	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	31	85	78	20	20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD																																

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 2932 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source heigth ≥ 100 m

Smoothed frequency distribution of wind velocity (kts)/wind direction (^{o}) for the KLUG-stability class I.

(MANIER)

(NACH MANIER)

	0,1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
WS	1463	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	39	48	35	67	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	48	58	92	87	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	29	144	142	159	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4	39	202	239	188	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5	77	250	296	250	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	135	284	308	303	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	116	159	246	197	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	48	130	123	135	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	58	106	116	91	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	48	72	85	43	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	19	48	31	34	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	39	34	35	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	58	24	19	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	58	14	8	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	39	19	15	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	10	29	15	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	19	34	23	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	58	87	39	43	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	96	96	92	63	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	67	101	92	111	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	48	91	119	120	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	48	67	85	96	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
23	39	48	46	34	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
24	39	24	31	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
25	19	19	12	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26	10	14	19	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
27	*	14	23	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	10	8	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	*	8	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	*	*	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
31	10	*	*	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
32	10	5	12	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	5	8	14	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	10	4	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	14	12	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	10	34	31	34	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	19	39	77	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

DD

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 519 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

≥ 100 m

Source height

Smoothed frequency distribution of wind velocity (kts)/wind direction (°) for the KLUG-stability class II.

(MANIER)

(NACH MANIER)

	0.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
WS	889	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
1	68	39	35	46	39	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
2	48	44	77	66	93	53	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
3	48	68	73	120	108	126	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
4	77	68	97	116	186	135	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
5	116	77	116	162	190	174	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
6	116	82	93	147	166	116	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
7	77	48	62	97	104	63	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
8	77	29	46	50	62	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
9	77	48	39	46	31	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
10	58	53	39	27	23	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
11	48	48	58	19	15	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
12	39	73	43	39	8	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
13	10	24	43	8	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
14	*	34	15	8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
15	19	34	27	12	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
16	29	34	19	15	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
17	19	34	31	12	27	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
18	58	53	39	70	43	48	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
19	68	53	81	77	116	82	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
20	29	48	70	97	93	102	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
21	39	48	62	73	77	82	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
22	39	29	66	70	73	68	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
23	29	34	54	85	54	44	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
24	19	34	58	89	46	29	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
25	*	10	50	62	46	24	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
26	*	10	8	39	12	29	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
27	*	*	15	8	19	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
28	*	10	8	23	8	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
29	10	*	15	8	12	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
30	19	5	12	12	12	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
31	19	5	8	8	12	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
32	10	*	12	12	19	34	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
33	*	10	12	8	19	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
34	10	5	15	4	8	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
35	10	10	12	15	8	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
36	29	15	23	15	23	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
UW	*	39	77	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
DD																																

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 517 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source height ≥ 100 m

Smoothed frequency distribution of wind velocity (kts), wind direction (°) for the KLUG-stability class III.1 (MANIER)

(NACH MANIER)

	0.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
WS	37	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1	*	2	15	20	17	20	15	20	26	33	26	20	19	6	9	6	2	4	2	*	*	*	*	*	*	*	*	*	*	*	*	*
2	5	5	7	22	19	24	37	41	63	76	69	63	46	26	22	19	19	9	6	2	*	*	*	*	*	*	*	*	*	*	*	*
3	5	2	13	11	26	30	45	46	80	85	76	78	56	33	22	24	19	15	4	*	*	*	*	*	*	*	*	*	*	*	*	*
4	*	2	4	19	50	52	48	58	72	72	58	48	50	19	20	19	22	9	2	*	*	*	*	*	*	*	*	*	*	*	*	*
5	*	*	4	41	74	71	50	32	48	39	17	28	13	11	6	7	7	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	5	*	6	26	59	43	33	17	26	15	11	6	7	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	5	2	11	19	30	24	19	17	13	7	4	6	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	*	9	13	22	30	15	22	7	9	6	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	*	7	13	22	26	28	6	7	9	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	5	9	11	15	28	13	9	6	4	6	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	9	7	7	7	7	9	2	2	6	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	5	7	6	4	6	2	2	2	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	5	5	2	2	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	5	2	4	2	*	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	*	5	6	4	2	2	*	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	*	2	4	4	4	6	2	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	14	*	4	2	9	13	6	*	4	2	2	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	19	2	4	6	22	33	20	15	9	11	6	6	6	6	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	5	2	6	17	48	50	59	46	43	24	19	11	15	9	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	*	2	7	26	50	65	76	93	85	89	48	24	26	13	6	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	5	*	7	30	65	63	95	102	145	121	93	69	37	28	15	15	13	6	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	9	5	2	20	43	50	67	85	93	128	100	74	72	35	35	28	35	17	6	6	2	*	6	*	2	*	*	*	*	*	*	*
23	5	5	7	6	22	30	41	43	74	67	76	84	59	54	43	46	35	26	19	11	9	7	6	11	2	2	4	*	*	*	*	*
24	*	9	7	7	17	19	35	30	39	52	46	58	52	54	52	32	39	20	15	11	4	2	9	4	7	4	6	4	*	*	*	*
25	*	5	7	9	11	17	13	20	39	35	50	41	50	37	33	28	26	26	17	6	2	*	*	6	2	4	6	2	*	*	*	*
26	*	*	7	2	6	7	7	17	33	43	33	41	26	35	20	17	28	22	11	2	*	*	*	*	2	*	2	*	*	*	*	*
27	*	5	2	4	2	4	17	15	35	26	19	11	19	13	11	9	15	11	6	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	2	4	*	*	9	13	20	20	20	7	9	11	15	7	2	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	2	2	*	*	4	13	7	24	15	11	4	9	6	4	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	2	4	2	6	6	9	15	19	32	11	7	2	2	*	*	*	2	2	2	*	*	*	*	*	*	*	*	*	*	*	*
31	*	2	4	6	6	11	7	2	26	19	15	6	4	2	*	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*
32	*	*	2	2	13	11	11	15	15	22	9	2	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	2	*	4	4	9	9	6	17	11	6	4	6	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	2	4	2	4	2	4	6	4	4	6	6	9	7	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	5	4	9	*	2	2	*	6	4	2	4	7	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	*	7	13	19	13	4	7	6	9	7	6	6	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	*	*	19	*	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD																																

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 1077 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source height ≥ 100 m

Smoothed frequency distribution of wind velocity (kts)/wind direction (°) for the KLUG-stability class III 2 (MANIER)

(NACH MANIER)

WS \ DD	0,1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
	63	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
1	*	21	29	29	13	17	33	38	13	13	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
2	*	37	38	38	58	38	63	71	38	*	4	4	*	*	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
3	*	16	33	58	54	79	79	88	33	13	4	8	8	*	8	8	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	
4	*	21	17	33	88	67	79	71	46	13	8	13	17	13	8	13	8	4	4	*	*	*	*	*	*	*	*	*	*	*	*	
5	10	16	29	58	63	75	58	58	21	13	4	13	17	13	8	8	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	
6	10	21	42	54	71	58	50	38	17	4	*	*	13	4	4	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
7	21	10	21	42	33	46	29	25	8	4	*	4	4	4	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
8	21	21	13	25	50	42	29	21	21	13	4	*	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
9	10	16	29	29	46	46	33	21	33	17	4	*	4	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
10	21	31	4	21	25	29	21	42	25	17	*	*	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
11	10	10	25	13	21	13	25	17	25	8	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
12	*	21	17	25	21	13	13	13	13	17	13	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
13	10	5	13	13	8	8	4	4	4	8	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
14	10	*	13	4	8	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
15	*	5	4	13	8	8	*	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
16	*	5	4	8	13	17	4	4	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
17	*	10	8	4	17	17	13	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
18	10	16	13	21	25	25	25	17	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
19	21	21	33	63	58	50	54	33	13	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
20	31	10	46	58	75	58	79	67	17	4	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
21	21	26	42	75	79	92	146	109	33	8	8	8	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
22	*	21	63	67	92	138	171	138	42	8	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
23	*	31	46	63	71	88	159	92	29	8	8	*	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
24	*	21	50	38	50	75	88	75	8	8	*	*	4	4	8	*	*	*	*	*	*	*	*	4	*	*	*	*	*	*	*	
25	10	21	33	58	63	63	92	54	13	*	*	*	*	8	4	8	*	*	*	*	*	*	4	4	4	*	*	*	*	*	*	
26	10	10	25	46	63	58	75	46	21	*	*	*	*	*	8	4	4	*	*	*	*	*	*	4	*	*	*	*	*	*	*	
27	*	5	13	25	29	29	38	38	8	4	*	*	*	*	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
28	*	*	13	8	8	8	29	8	8	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
29	*	5	8	8	8	13	25	17	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
30	*	5	8	8	13	29	42	21	8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
31	*	*	4	8	25	50	50	29	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
32	*	5	*	4	25	50	42	21	4	4	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
33	*	5	13	13	25	42	42	17	13	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
34	*	10	13	13	13	25	21	25	8	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
35	*	16	13	8	*	13	17	17	8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
36	*	16	21	8	13	8	17	17	13	*	4	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
UW	*	63	63	21	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	

DD

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 479 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source height ≥ 100 m

Smoothed frequency distribution of wind velocity (kts)/wind direction (°) for the KLUG-stability class IV (MANIER)

(NACH MANIER)

WS	0.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
1	*	28	30	37	15	22	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	19	46	67	37	59	45	30	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	37	65	59	82	52	74	37	37	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4	19	65	67	67	89	52	89	46	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5	*	74	82	134	111	104	104	102	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	37	56	96	111	119	104	119	102	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	74	56	30	59	59	37	74	46	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	56	46	30	30	59	59	37	37	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	56	37	22	30	67	52	37	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	93	28	7	22	37	30	7	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	74	9	*	7	30	*	7	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	56	9	7	15	22	22	*	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	56	9	*	7	30	30	7	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	37	*	*	*	30	22	22	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	19	28	*	7	7	22	*	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	*	37	22	*	7	7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	37	56	7	*	7	7	7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	74	37	15	*	7	15	*	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	74	28	22	15	22	30	15	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	37	65	22	45	74	30	22	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	*	46	82	74	82	82	45	37	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	19	93	45	82	119	82	74	74	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
23	19	37	45	59	96	59	45	28	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
24	*	56	30	59	89	52	22	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
25	*	65	30	30	45	30	22	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26	19	65	30	*	15	15	22	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
27	19	46	22	15	15	15	15	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	19	7	7	7	7	7	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	*	7	7	7	*	*	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	*	*	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
31	*	*	7	7	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
32	*	*	*	15	15	7	7	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	9	*	7	15	15	15	19	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	9	7	7	7	*	7	9	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	9	15	7	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	*	9	22	22	7	15	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	223	594	334	148	74	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD																																

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 269 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Period 8/71 - 7/72

Source height ≥ 100 m

Smoothed frequency distribution of wind velocity (kts)/wind direction (°) for the KLUG-stability class V (MANIER)

(NACH MANIER)

WS	0.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
1	*	*	*	80	80	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	80	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	*	*	*	*	80	159	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4	*	*	*	*	80	318	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5	*	*	*	*	159	239	159	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	*	*	*	*	*	159	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	*	*	*	*	*	80	*	99	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	*	*	80	*	80	80	159	99	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	*	99	80	80	*	80	*	99	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	*	*	*	*	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	*	*	*	*	*	80	159	99	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	*	*	*	*	*	80	159	99	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	*	*	*	*	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	*	*	*	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	*	*	*	*	80	80	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	*	*	*	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	*	*	80	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	*	99	80	80	80	159	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
23	*	*	80	*	159	159	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
24	*	*	*	80	80	159	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
25	*	*	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
27	*	99	80	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
31	*	99	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
32	*	99	80	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	99	*	80	80	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	*	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	*	*	*	*	80	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UM	795	795	398	398	398	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD																																

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 25 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

Station 637 Frankfurt /Main

Source height

Smoothed frequency distribution of wind velocity (kts)/wind direction (°) for the KLUG-stability class N=9 (MANIER)

Period 8/71 - 7/72

≥ 100 m

(NACH MANIER)

WS	0.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	G30	FF
1	1457	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	*	52	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
4	104	156	125	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5	104	104	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	*	104	42	*	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7	*	104	42	*	83	42	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
8	104	52	*	42	42	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
9	104	*	*	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10	208	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
11	208	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12	104	52	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
13	104	104	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14	*	101	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
15	*	52	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
16	104	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
17	104	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18	*	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19	*	104	42	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20	104	52	125	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21	104	104	125	125	42	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22	*	52	166	125	166	42	42	83	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
23	*	156	166	291	166	125	125	42	83	42	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
24	*	208	291	250	291	83	42	83	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
25	*	104	125	208	125	42	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26	*	*	83	83	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
27	*	52	42	83	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
28	*	*	42	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
31	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
32	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
35	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
36	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
UW	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
DD																																

ANZAHL DER AUSGEWERTETEN (FF,DD)-WERTE 48 DIE HAEUFIGKEITEN SIND IN 1/100 PROZENT ANGEGEBEN

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3.3 Model descriptions

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Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Sivertsen; Norway (KILDER)

GAUSSIAN MULTIPLE SOURCE MODEL: "KILDER"

Established at Norwegian Institute for Air Research, 1974

ABSTRACT:

A model based on Gaussian consentration distribution for calculating short term or long term groundlevel concentrations from point and area sources. The model is quasi-stationar and applies to inert gas (without reactions).

Characterstics:

- area sources are simulated as circular
- topographical features can be included to a certain degree
- plume rise is calculated by 3 different formulae dependent on heat emission
- dry deposition can be simulated

RESULTS:

The concentration at each grid point (at groundlevel or specified level) is calculated and printed out for the sum of all sources. Grid spacing can be varied (by map scaling). Concentrations can represent annual, seasonal or hourly averages.

APPLICATION:

SO_2 and NO_x concentrations in Telemark, southern Norway.

BASIC EQUATIONS:

Point sources (continuous emission)

$$\chi = \frac{Q \cdot S}{2\pi\sigma_y\sigma_z u} \exp\left(-\frac{y^2}{2\sigma_y{}^2}\right)$$

where

$$S = \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z{}^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z{}^2}\right)\right]$$

for long time average concentrations sector-averaging is used:

$$\chi = \frac{Q \cdot N \cdot S}{(2\pi)^{3/2}\sigma_z \cdot l \cdot u}$$

where

$l = (x^2+y^2)^{1/2}$

N = number of sectors for given meteorological data

Area sources

Treated as virtual point sources with dispersion parameters

$$\sigma_y = A \cdot (x+x_y)^p$$

$$\sigma_z = B \cdot (x+x_z)^r$$

where

$$x_y = \left(\frac{b}{4.3A}\right)^{1/p}$$

$$x_z = \left(\frac{h}{4.3B}\right)^{1/r}$$

b = width of area

h = height of area

PLUME RISE FORMULAES:

$$Q_H = \text{heat emission} \left[\text{cal/s}\right]$$

Unstable and neutral air: $Q_H < 2 \cdot 10^5 \quad : \Delta h = \frac{1}{u}\left[1.5 \cdot d \cdot v_g + 4 \cdot 10^{-5}\ Q_H\right]$

$$2 \cdot 10^5 < Q_H < 7 \cdot 10^6 \quad : \Delta h = \frac{1}{u}\left[1.5 \cdot d \cdot v_g + 65 \cdot d^{3/2} \left(\frac{T_s - T}{T_s}\right)^{1/4}\right]$$

$$Q_H > 7 \cdot 10^6 \quad : \Delta h = \frac{F^{1/3}}{u} (10 h_s)^{2/3}$$

Stable air: $\Delta h = 2.9 \left(\frac{F}{u \cdot s}\right)^{1/3}$

where $s = \frac{g}{T} \frac{\partial \theta}{\partial z}$

$$F = g \cdot v_g (d/2)^2\ \Delta T / T_s$$

METEOROLOGICAL PARAMETERS:

Diffusion parameters

In the version tested in Telemark Singer and Smith's values from Brookhaven is used:

$$\sigma = Ax^P$$

can be run on McElroy Pooler's values for low stacks.

Horizontal wind field

Simulated by using 30° sectors for long time averages, homogeneous wind given at 1° accuracy as input for short time average concentrations.

Wind profile

Constant wind with height in this version of the model.

Stability class

4 stability classes; unstable, neutral, light stable, very stable. The stability class is selected based on input of potential temperature difference with height ($\partial\theta/\partial z$) for short time average concentrations. For long time average concentrations the stability class is given as 1 to 4.

Mixing height

Can be specified as height to "inversion led".

INPUT DATA:

Emission

Emission inventory for point and area sources (source strength) must be specified in the given grid system (map scale). Emissions considered continuous. Stack data (v, d, H, T) as input for point sources.

Meteorology

For long time average concentrations give as input joint frequency distribution of wind direction (12 classes), stability (4 classes) and wind speed (4 classes or as average for each direction/stability class).

For short averaging time wind speed and direction, stability ($\partial\theta/\partial z$ or 1-4) and mixing height are given as input for each hour.

Program description

Program description and users manual is available in Norwegian. (J. Schjoldager, NILU TN, No. 2/75, Nov. 1974).

Emission sources and receptor points are limited in existing version, but can easily be expanded.

For chapter 1.3: "Differences between the Models" in Techn. Doc. M.P. 1/1975 1.1.G., the following could be added for the model "KILDER":

1.	Area Source Simulation	: Virtual point source.	
2.	Plume Rise Formulae	: Holland (small sources) Stümke	Neutral unstable air
		Briggs (large sources, and stable air)	
3.	Diffusion Function	: $\sigma(x) = a \cdot x^p$ (Singer/Smith)	
4.	Stability Classification	: 4 classes ($\partial\theta/\partial z$)	
5.	Reduction rate equation	: Dry deposition as reflection factor	
6.	Method for calculating Frequency distribution	: Concentration for each stability/ wind class stored by magnitude	
7.	Specification of wind speed	: Constant with height	
8.	Special additional input	: Temperatures at two (or more levels), scale of printout map, topographical features	

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Nieuwstadt; The Netherlands (KNMI)

KNMI-CLIMATOLOGICAL DISPERSION MODEL

Type Gaussian model
Nieuwstadt (1974)
long-term model

Abstract Two versions of the model are available.
Both versions:
a long-term averaged model for calculation of long-term (monthly, seasonal, yearly) averaged concentrations from the emissions of point and area sources.
Characteristic for the model is:

a. Simulation of area sources by the virtual point source model.
b. A power law formulation of the vertical wind profile.
c. The influence of decay and deposition can be taken into account.
d. For each wind speed and stability class a distribution of mixing heights can be taken into account.

Version I:

a. Two different sets of dispersion coefficients are used depending on the physical stack height.
b. Several plumerise formulas are available.

Version II:

a. The dispersion coefficients are determined with an interpolation scheme based on effective stack height.
b. Plumerise formula of Briggs.
c. In the dispersion coefficients for sources near the ground the surface roughness is taken into account.

Results

Both versions:

For each gridpoint of the area under consideration the ground level concentration or the concentration at any other level can be calculated.

At selected receptor points the total concentration and the contribution of all sources to the total concentration is determined.

At the points of a maximum value in the concentration pattern the contribution of all sources to this maximum is determined.

A program to draw isolines of concentration is available.

Application

Version I:

SO_2 concentrations:

Sloe-gebied (Zeeland, Neth.)

Amsterdam-Haarlem area (Neth.)

Rijnmond area (Neth.).

Basic equations : Both versions.

Point sources

$$C(x,y,z) = \sum_{n=1}^{N} \sum_{s} \sum_{w} \frac{Q\,F(\theta_i,s,w)}{\sqrt{2\pi}\; u_{w,s}\; \sigma_{z_s}\; \varepsilon\, r} \left\{ e^{-\frac{(z+H_{s,w})^2}{2\sigma_{z_s}^2}} + e^{-\frac{(z-H_{s,w})^2}{2\sigma_{z_s}^2}} \right\} \quad (A)$$

$F(\theta_i,s,w)$ = frequency of wind direction class θ_i, stability class s and windspeed class w.

$u_{w,s}$ = representative windspeed for windspeed class w and stability class s.

σ_{z_s} = vertical dispersion parameter for stability class s.

ε = $2\pi/12$ (12 wind direction classes).

r = distance between source and the point (x,y,z).

$H_{s,w}$ = effective source height, dependent on stability s and windspeed w.

N = number of point sources.

Area source

Virtual point source model.

A point source is calculated with the total emission of the area source in the centre of the area source.
Modification of σ_z calculation: to calculate σ_z at the distance r from the source, a distance r_o is added to r, so that $\sigma_z(r+r_o)$ is calculated. The distance r_o is determined from $\sigma_z(r_o) = \sigma_o$, where σ_o is specified.

For $\sigma_z > 1.3$ L (L is the mixing height) the formula for the point source becomes:

$$C(x,y,z) = \sum_{n=1}^{N} \sum_{s} \sum_{w} \frac{Q\,F(\theta_i, s, w)}{u_{w,s}\ \varepsilon\, r} \sum_{L_i} f_{w,s}(L_i)\,\frac{1}{L_i} \qquad (B)$$

L = mixing height.

$f_{w,s}$ = frequency distribution function of mixing height classes (5) for each windspeed and stability class.

Between (A) and (B) interpolation equations are used.

Plumerise formula

Version I: I Briggs (2 versions)
II Stümke
III Concawe
IV K.S.L.A.

Version II: Briggs

a) $\Delta h = 1.6\, F^{1/3}\, (3.5\, x^*)^{2/3}\, u^{-1}$ $\quad x^* = 14\, F^{5/8}\ F \leqslant 55$
$x^* = 34\, F^{2/5}\ F > 55$

b) $\Delta h = 2.9\, (F/us)^{1/3}$ $\quad s = 1.3\ 10^{-4}$

From a and b the lowest value of Δh is chosen.

Meteorological parameters

Diffusion parameters

Version I.

a) low sources (physical stack height h<ca. 50 m).

Pasquill-Gifford

$$\sigma_z = ar^b + c$$

S	r <1000 m a	b	c	r >1000 m a	b	c
A*	9.38×10^{-5}	2.2217	16.3731	2.4×10^{-4}	2.094	-9.600
B	0.0371	0.1530	3.1914	0.054	1.0997	2.5397
C	0.0992	0.9289	0.2444	0.0991	0.9255	1.7383
D	0.2066	0.7338	-1.3659	0.9248	0.5474	-9.0641
E	0.1975	0.6865	-1.1644	2.3441	0.4026	-16.3186
F	0.09842	0.7210	-0.3231	6.5286	0.2593	-25.1583

* A r <400 m: $a=6.0 \times 10^{-3}$; b=1.5548; c=6.2686

The transport wind is determined at physical stack height.

b) high sources (physical stack height h>ca. 50 m).

Singer and Smith

$$\sigma_z = ar^b + c$$

Stability	a	b	c	Stability
A	0.411	0.907	0	B_2
B	0.411	0.907	0	B_2
C	0.326	0.859	0	B_1
D ($u < 5.5\ ms^{-1}$)	0.326	0.859	0	B_1
D ($u > 5.5\ ms^{-1}$)	0.223	0.776	0	C
E	0.062	0.709	0	D
F	0.062	0.709	0	D

Transport windspeed according to Singer-Smith.

Version II.

a) effective stack height $H \leqslant 10$ m.
Pasquill-Gifford (cf. table)
transport velocity at 10 m.

b) effective stack height $H \geqslant 100$ m.
Singer and Smith (cf. table)
transport velocity according to Singer and Smith.

c) effective stack height $10 < H < 100$ m.
Linear interpolation between a and b of the dispersion coefficient and the transport velocity.

The roughness of the area is taken into account by multiplying the dispersion coefficients of Pasquill-Gifford by a factor for each stability class.

Horizontal wind field

Both versions:
Simulated by using 30° sectors for the wind rose, subdivision into 3 windspeed classes.
For each windspeed class the representative windspeed $(1/[\overline{1/u}])$ has been determined.

Wind profile

Both versions: $u = u_o(\frac{z}{z_o})^m$

stability class	A	B	C	D	E	F
value of m	0.10	0.10	0.16	0.16	0.30	0.30

Stability class

Both versions:
Pasquill-classification A - F (6 classes)
unstable stable

Mixing height

Both versions:
is described by a distribution for each windspeed and stability class.

Input data

Emission

Both versions:
Complete emission inventory for point, area and line sources (source strength, area size).
Additional stack data for singular emittents.

h = physical stack height
v = speed of emission
d = stack diameter
T = temperature

} or Q_H = heat emission

Meteorology

Both versions:
Three parametric (joint) frequency distribution of wind direction, windspeed and stability class, i.e. (12 x 3 x 6 = 216 values).
For each windspeed and stability class a distribution of mixing height classes (max. 5), for instance for each stability class one mixing height.

Program description

Theoretical description of the Gaussian plume model. User's manual with full program description and input orders.
Output in tables by line printer and line printer plots.

Validation of the model

Version I:
The validation of the model to the Amsterdam-Haarlem region is given in F.T.M. Nieuwstadt and H. van Dop: "Validation of a multiple source diffusion model based on the Gaussian plume model", 6th NATO/CCMS International Technical Meeting, 24-26 September 1975, Frankfurt/M.

The validation of the model to the Rijnmond area will be published later.

Literature

F.T.M. Nieuwstadt:
Stability classes and dispersion coefficients (in Dutch).
KNMI Scientific Report W.R. 75-3 (1975) 36 pp.

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The Gaussian plume model (in Dutch).
KNMI Scientific Report W.R. 74-15 (1974) 52 pp.

E.H.J. Vermaas, F.T.M. Nieuwstadt:
Manual for the Gaussian plume model computer-program.
KNMI Scientific Report W.R. 75-7 (1975) 74 pp.

F.T.M. Nieuwstadt, H. van Dop:
Validation of a multiple source diffusion model based on the Gaussian plume model.
Proc. 6th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Frankfurt, 24-26 Sept. 1975, NATO/CCMS, to be published.

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Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Junod, Liechti; Switzerland (Pollux)

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SOCIETE D'ETUDE DE L'ENVIRONNEMENT

MULTIPLE SOURCE MODEL
P O L L U X

Succinct Description

SEDE S.A.

Jean-Michel Liechti

Vevey, September 1976

MULTIPLE SOURCE MODEL "POLLUX"

developped by Société d'Etude de l'Environnement SA (SEDE SA), Vevey, Switzerland, 1975.

ABSTRACT

The model calculates short term or long term groundlevel concentrations from point and area sources as well as the spatial frequency distribution. The distributions can be weighted by population. POLLUX contains moreover a two-dimensional box model for the cases of stagnation and a Q/u-model. POLLUX allows to introduce input-data as data groups with outputs for each group and for total of all the groups. Flexibility is further enhanced by the use of parameter cards.

Example of applications :

Centrale Chaleur-Force du Sud-Ouest Lausannois.

Dispersion des polluants fluorés de l'Usine d'aluminium de Martigny.

Luftverschmutzung im Kanton Zürich, Erfassung des Ist-Zustandes.

* * *

BASIC EQUATIONS **Point sources** :

$$\chi = \frac{Q}{u} Y(y)\, Z(z)$$

$$Y(y) = \frac{1}{\sqrt{2\pi}\sigma_y} \exp\left(\frac{-y^2}{2\sigma_y^2}\right)$$

$$Z(z) = \frac{1}{\sqrt{2\pi}\sigma_z} \left(\exp \frac{-(z-h)^2}{2\sigma_z^2} + \exp \frac{-(z+h)^2}{2\sigma_z^2}\right)$$

Area sources :

The area source is simulated by a line source which is always perpendicular to the wind.

$$Y_D(y) = \frac{1}{2(y_2-y_1)} \left(\mathrm{erf}\, \frac{y_2}{\sqrt{2}\sigma_y} - \mathrm{erf}\, \frac{y_1}{\sqrt{2}\sigma_y}\right)$$

D is the source size

$y_2 = y + D/2$

$y_1 = y - D/2$

Z(z) has the same form as for the point sources.

Plume rise :

For point sources $\Delta h = E/u^{\alpha}$

$\alpha = 1$ for unstable and neutral atmosphere

$\alpha = 1/3$ for stable and very stable atmosphere

E is an input data calculated according to BRIGGS

For area sources $\Delta h = \frac{E}{u} \frac{1}{1 + \left(\frac{u}{u_c}\right)^{\nu}}$

$u_c = 3$ m/s

$\nu = 2$

E is an input data

METEOROLOGICAL PARAMETERS

Diffusion parameter

$$\sigma_y = \frac{C_y}{\sqrt{2}}\left(x + x_{yo}\right)^{1-n/2} \qquad \sigma_z = \frac{C_z}{\sqrt{2}}\left(x + x_{zo}\right)^{1-m/2}$$

For individual sources : Coefficients as recommanded by the Swiss Meteorological Institute.

Stability Class	C_y	C_z	n = m
B + C	0,26	0,25	0,14
D	0,30	0,21	0,36
E	0,40	0,16	0,52
F	0,48	0,11	0,58

For zone sources (group of area sources) : Coefficients according to the St-Louis Study, 1968.

Stability Class	C_y	C_z	n	m
B	1,64	0,07	-0,56	0,48
C	1,57	0,13	-0,22	0,52
D	2,08	1,05	0,52	0,66
E	0,90	1,22	0,82	0,56

Penetration of elevated inversions

POLLUX calculates $\Delta h_m = \frac{1}{2}\left(\Delta h_{neutral} + \Delta h_{very\ stable}\right)$

H : height of the inversion

h_o : stack height

When $\frac{1}{2}\Delta h_m > H - h_o$, the contribution of the source is cancelled

When $\frac{1}{2}\Delta h_m < H - h_o$, the source is considered to be on a height H and the source-strength is multiplied by γ where :

$\gamma = 1$ when $H > h_o + 1{,}5\,\Delta h_m$

$\gamma = (H - h_o - \frac{1}{2}\Delta h_m)/\Delta h_m$ if $H < h_o + 1{,}5\,\Delta h_m$

Vertical wind profile

$$u(z) = u(z_o) \left(\frac{z}{z_o}\right)^p$$

with stability dependant exponent p

EMISSION PARAMETER Load factor

POLLUX allows to vary the source strength linearly.

GF = group factor

EF = episode factor

Q_o = source strength

A0, A1, A2 : Parameters for the calculation of the source load

$\alpha_g = A0 + (1 - A0)\ GF$

$\alpha_e = A1 + (A2 - A1)\ EF$

The source load is $\alpha = \alpha_g \cdot \alpha_e$

POLLUX than uses $Q = \alpha Q_o$ and $E = \alpha^{1/3} E_o$

IMMISSION PARAMETER Calibration factor and background pollution

The calculated concentration χ_o can be transformed according to

$$\chi = \mu \chi_o + \chi_f$$

μ is a calibration factor

χ_f is the background pollution

INPUT DATA Grid

The grid is defined by giving the coordinates of two extreme points of the zone for which the calculations are to be made and the scale. Grid spacing is predicated on these data and is automatically chosen by the program .

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Meteorology

Each meteorological episode is given by an input card. The latter contains the wind speed and direction, the wind sector, the stability class, the mixing height, the episode frequency and the episode factor.

Sources

Each individual source is given by an input card. It contains the coordinates, the height, the strength, E for each class of stability, σ_{yo} and σ_{zo}, the load parameters AO, A1, A2 and the source size if it is an area source.

The zone sources are given by a first card which defines the standard source : source size and height, E for each class of stability, σ_{yo} and σ_{zo}, AO, A1, A2. The following cards contain the strength of the sources in the zone.

Population

The population is introduced by a first card which gives the size of the population element (square). The following cards contain the population of each element.

Diffusion parameters

For each class of stability, other diffusion coefficients can be introduced for individual and zone sources.

PROGRAM DESCRIPTION User's manual with input orders.

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Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Berger, Demuth, Jacquardt; Belgium

Université Catholique de Louvain
Institut d'Astronomie et de Géophysique
Georges Lemaitre

LONG PERIOD AVERAGE DISPERSION MODEL

A. BERGER, CL. DEMUTH, Y. JACQUART

Technical Document 1/1976 M.P. 2.4
Principles of Multiple Source Air Quality Modeling
NATO/CCMS AIR POLLUTION STUDY
MODELING PANEL

NAME : LONG PERIOD AVERAGE DISPERSION MODEL (LPADM) (bi-gaussian version)

TYPE : Analytical solution of the stationary diffusion equation where K_y and K_z are function of the downwind distance.

ABSTRACT :

1. The LPADM computes ground level concentration for one (or many) pollutant released from point and area sources. The diffusion formula is an exact solution of

$$U \frac{\delta X}{\delta x} = K_y(x) \frac{\delta^2 X}{\delta y^2} + K_z(x) \frac{\delta^2 X}{\delta z^2}$$

As that solution has a form similar to the usual Gaussian Plume formula, it is classed as a bi-Gaussian model. The algorithm of the program is based upon the CDM (Busse and Zimmerman , 1973)

2. Characteritics of the model
   - any plume rise formula can be used.
   - simulation of area sources
   - diffusion parameters are expressed as $\sigma = ax^b$, where a and b are function of the stability class
   - mixing height depends upon the stability class and upon the observed mixing height during the afternoon and at night.
   - power law for the vertical wind profile.
   - consideration of chemical reaction (half-life).
   - flat terrain only (topography cannot be taken into account).
   - dry deposition cannot be taken into account.
   - this model cannot be used for calm wind situations.
   - grid mesh (must be square of any dimension).
   - illimited number of point sources.
   - illimited number of area sources.

3. Results : From a joint frequency distribution F (is, id, iw) of the different meteorological situations defined from the wind

direction (id), wind speed (iw) and stability class (is), and recorded over a given extended period of time (e.g month, season, year), the model gives a map of the mean concentration over a given area, the frequency distribution of concentration at any grid points and/or at any other selected points (where generally concentration has been measured).

BASIC EQUATIONS

1. Point sources .

The ground level concentration over a flat terrain is estimated (for N point sources ip) from :

$$\chi = \sum_{ip=1}^{N} \sum_{is,id,iw} Y\,(ip,is,id,iw)\; Z\,(ip,is,id,iw) \qquad \text{where} \qquad (1)$$

$$Y = \frac{16}{2\pi}\, F(is,id,iw)\, \frac{1}{2x_{ip}} \left[\operatorname{erf} \frac{(x\phi + y)}{\sqrt{2}\,\sigma_y\,(x,is)} + \operatorname{erf} \frac{(x\phi - y)}{\sqrt{2}\,\sigma_y(x,is)} \right] \qquad (2)$$

$$Z = \frac{2Q_{ip}}{U\,(is,iw)\sqrt{2\pi}\;\sigma_z\;(x,is)} \left[\exp\left(-\frac{H^2}{2\sigma_z^{\,2}\,(x,is)}\right) + \sum_{n=1}^{\infty} \exp\left[-\frac{(H-2nL)^2}{2\sigma_z^{\,2}\,(x,is)}\right] + \sum_{n=1}^{\infty} \exp\left[-\frac{(H+2nL)}{2\sigma_z^{\,2}\,(x,is)}\right] \right] \qquad (3a)$$

$$Z = \frac{Q_{ip}}{U\,(is,iw)\;L\,(is)} \left[1 + 2 \sum_{n=1}^{\infty} \cos\frac{n\,\pi\,H}{L}\; \exp\left(-\frac{n^2\,\pi^2\,\sigma_z^{\,2}}{2L^2}\right) \right] \qquad (3b)$$

Y = is an average of the crosswind gaussian dispersion for long period of time.

is = stability class id = wind direction class iw = wind speed class.

x_{ip} , y_{ip} : downwind and crosswind distance from the source ip to the receptor.

ϕ : fluctuation of the wind direction around the bisectrix of the wind sector.

erf(θ) : $\frac{2}{\sqrt{\pi}} \int_0^{\theta} e^{-t^2} dt$ (error function)

χ : average concentration of pollutant j at the point (x,y) (gr/sec).

Q_{ip} : emission rate of pollutant j. (gr/sec).

L (is) : mixing height as a function of the stability class (is). (m)

H(is,iw) : effective stack height. $H = \Delta h + h_g$ (m)

Δh : plume rise

h_g : geometrical stack height

U(is,iw) : mean horizontal wind speed at the top of the stack.

σ_y (x,is) , σ_z (x,is) : horizontal crosswind and vertical diffusion parameters.

F (is,id,iw) : joint frequency distribution of wind direction id, wind speed iw, and stability class is.

Z is determined from

(3a) without reflection terms (no summation) if $0 < \frac{\sigma_z}{L} \leqslant 0.4 \left(1 - \frac{H}{2L}\right)$

(3a) with n = 2 if $0.4 \left(1 - \frac{H}{2L}\right) \leqslant \frac{\sigma_z}{L} < 0.8$

(3b) with n = 1 if $0.8 \leqslant \frac{\sigma_z}{L} < 1.6$

(3b) without reflection terms (no summation) if $1.6 \leqslant \frac{\sigma_z}{L}$

2. Area sources .

Numerical integration of the point sources formula where the asymptotic value of Y is used : $Y = \frac{16}{2\pi} \; F\,(is,id,iw) \; . \; \frac{1}{x_{ip}}$

3. Plume rise formula.

a. Point sources :

1) Briggs : unstable conditions (A,B,C,D) :

$$\Delta h.U = \begin{cases} 1.6\, F^{1/3} (3.5X^*)^{2/3} & \text{if} \quad x > 3.5\, X^* \\ 1.6\, F^{1/3}\, x^{2/3} & \text{if} \quad x \leqslant 3.5\, X^* \end{cases} \quad \text{where} \quad X^* = \begin{cases} 14\, F^{5/8} & \text{if } F < 55 \\ 34\, F^{2/5} & \text{if } F > 55 \end{cases}$$

stable conditions (E,F) :

$$\begin{cases} \Delta h = \dfrac{1.6}{U} F^{1/3}\, x^{2/3} \\ \Delta h_{max} = 2.4\, [F\, T_a \,/\, (g\, US)]^{1/3} \end{cases} \quad \text{where} \begin{cases} S = 0.02 \text{ for stability class} \\ S = 0.035 \text{ for stability class F} \end{cases}$$

2) Stumke II : $\Delta h.U = 1.5\, v_s d_s + 65\, d_s^{3/2}\, (\Delta T/T_s)^{1/4}$

3) K.L.S.A. (1974) :

$$\Delta h/d_s = 1.81\, v_s/U + [15.84 - (8.65 - 42.21 \frac{\Delta T}{T_s}) \sqrt{\frac{9.8 d_s}{U}}\,] \; .$$

$$[1 - \exp\{ - \frac{v_s}{U} (0.57 + 0.0175 \frac{9.8 d_s}{U})\}]$$

the buoyancy flux being given by :

$$F = g v_s \frac{d_s^2}{4} \frac{\Delta T}{T_s}$$

b. Area sources : the effective height is equal to the geometrical height of the area sources.

INPUT

1. Meteorological parameters :

- a three parameters joint frequency distribution F (is,id,iw). F is determined from the meteorological records through a program FIJK.
- mixing height in the afternoon (HT) and at night (HMIN).
- mean wind speed per wind speed class may be given for replacing the theoritical values fixed in Table 4.
- height at the anemometer level may be given for replacing the fixed value 10m.

a. Stability class :

the definition by Pasquill-Gifford (A-G) is used (Busse and Zimmerman, 1973).

8 classes are considered to take into account, as suggested by Calder (1971), the subdivision of class D into one for the day and another for the night. A definition of these classes can be found in Turner (1964). The meteorological parameters for the day and the night are : cloud cover, ceiling height, windspeed and insolation (given through the Solar Altitude).

Very often, it is possible to consider only 6 stability classes (as done in Table 3).

b. Diffusion parameters : $\sigma_z = a\,x^b$ $\sigma_y = \alpha\,x^\beta$

a,b,α,β after Pasquill-Gifford (Busse and Zimmerman, 1971) for h_g <50m
after Singer-Smith (Niewstadt and Van Dopp, 1975) for h_g ≥50m
(Tables 1 and 2).

c. Mixing height : L = L (is) = f (HT, HMIN) (Table 3)

HT is a mean value of the mixing height in the afternoon
HMIN is a mean value of the mixing height at night

Over the whole period considered, HT and HMIN are considered as constant (Holsworth, 1972).

d. Horizontal wind speed : 6 wind speed classes.
This number of wind speed classes is generally not equal to the number of stability classes.
For each class the boundaries and the mean wind speed is given in Table 4. This mean value is not the observed value over the given period but an apriori fixed one. (the observed value may easily be introduced).

e. Horizontal wind direction :

16 sectors (22°5) for the wind rose, the first one being centered upon the North.

f. Vertical wind profile : power law

$$u(z) = u(z_o) \left(\frac{z}{z_o} \right)^m$$

m is a function of the stability class (Table 3)

$u(z_o)$: wind speed at the anemometer level.
is also a function of the wind speed class (Table 4).

g. Transport wind speed : at the geometrical(or even effective) stack height : U (is,iw)
U is deduced from the power law wind profile.

2. Emission :

a. point source : inventory must be specified in the given grid system (map scale).

b. stack data : h_g : geometrical stack height.
v_s : speed of emission.
d_s : diameter of the orifice of the stack.
$\Delta T = T_s - T_a$
T_s : temperature of the stack gas
T_a : " of the ambient air.(ground level value is generally used but an interpolated value at level of the geometrical stack height can be computed

using a mean value of the temperature gradient for each stability class).

c. area source :

- inventory must be specified in the given grid system.
- grid mesh must be specified.
- these area sources must be square which length is equal to the grid mesh or an integer multiple of the grid mesh. Coordinates of the lower left corner must be given for each area source.

OUTPUT

Mean concentration at any point (grid point or other selected point given by their coordinates in the projection system used).
The map is drawn through a program MAP.

For any selected point , the concentration is given for all different meteorological situations, i.e. , χ corresponding to any fixed (is,id,iw) is printed out.
Another program (STTPL) computes the frequency distribution at these points, the regression line, the geometrical mean and the 98th percentile.

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Table 1 Pasquill-Gifford coefficients for the diffusion parameters.

stability class	x < 500		500 < x ≤ 5000		5000 ≤ x			
	a	b	a	b	a	b	α	β
A	0.0383	1.2812	$0.2539\ 10^{-3}$	2.0886	$0.2539\ 10^{-3}$	2.0886	0.3658	0.9031
B	0.1393	0.9467	$0.4936\ 10^{-1}$	1.1137	$0.4936\ 10^{-1}$	1.1137	0.2751	0.9031
C	0.1120	0.9100	0.1014	0.9260	0.1154	0.9109	0.2089	0.9031
D day	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642	0.1474	0.9031
D night	0.0818	0.8155	0.2527	0.6341	1.2969	0.4421		
E	0.0545	0.8124	0.2017	0.6020	1.5763	0.3406	0.1046	0.9031
F							0.0722	0.9031
G								

Table 2 Singer-Smith coefficients for the diffusion parameters.

stability class	a	b	α	β
A	0.411	0.907	0.40	0.91
B	0.411	0.907	0.40	0.91
C	0.326	0.859	0.36	0.86
D (< 11 knots)	0.326	0.859	0.36	0.86
D (≥ 11 knots)	0.223	0.776	0.32	0.78
E	0.062	0.709	0.31	0.71
F	0.062	0.709	0.31	0.71

Table 3 Vertical wind profile and mixing height.

stability class	is	exponent in the vertical wind profile: m	mixing height L
A	1	0.1	1.5 HT
B	2	0.15	HT
C	3	0.20	HT
D_{day}	4	0.25	HT
D_{night}	5	0.25	(HT+HMIN)/2
E, F, G	6	0.30	HMIN

Table 4 Wind speed classes.

boundaries (knots)	wind speed classes iw	$u(z_0)$ (m/sec)
0-3	1	1.5
4-6	2	2.46
7-10	3	4.47
11-16	4	6.93
17-21	5	9.61
> 21	6	12.52

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Kretzschmar, De Baere, Mertens,
Vanderven; Belgium

NATO / CCMS

AIR POLLUTION PILOT STUDY

FRANKFURT

BRIEF DESCRIPTION OF THE SCK/CEN's IMMISSION FREQUENCY DISTRIBUTION MODEL

by

J.G. Kretzschmar, G. De Baere, I. Mertens and J. Vandervee

May 1977.

Mol-Donk, 20,01,1976

MMUM 7

Type IMMISSION FREQUENCY DISTRIBUTION MODEL (IFDM)
S.C.K.-C.E.N. Belgium

Gaussian model (1972)

Abstract

The IFDM model calculates ground level concentrations for one pollutant coming from point and area sources

Characteristic for the model are the following steps :

- 1 : for a given set of emission data, pollution maps are calculated for specific combinations of representative meteorological situations.

  2 : on the basis of the actual meteorological data for a particular period in a given region, an ensemble of the relevant pollution maps is made.

- the plume rise formula of Slömke II is used.

- a vertical windprofile (exponential law) is applied.

- the pollutant is passive.

- the topography can be included.

- the earth surface and the top of the mixing layer are acting as perfect reflectors for the pollutant under investigation.

- area sources are simulated by touching circles wherein the population density can be considered homogeneous.

Results

For each grid point of a regular network with maximum 16 x 21 meshes of n km^2, complete statistics of individual concentrations for a given averaging time (1 hour $\leq t_{av} \leq$ 1 year) and for a specified period ($\leq$ 3 years) are calculated (averages, standard deviations, maxima and percentiles).

Applications

Evaluations of the influence of a new or existing point or area source upon the pollution levels in a given region.

Basic equations <u>Continuous point sources</u>

$$X_i(x,y,o) = Q_i \; \delta^{-1}(x,y,o)$$

$$= \frac{Q_i}{\pi \, \bar{u}(h_e) \, \sigma_y \, \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left(-\frac{h_e^2}{2\sigma_z^2}\right)$$

<u>Area sources</u>

$$X_i\,(o,o,o) = F \times \Big[(A_{1i} + A_{2i} h_e) + (B_{1i} + B_{2i} h_e) \sqrt{x_2}$$

$$+ (C_{1i} + C_{2i}\, h_e)\, x_2 \Big] / \bar{u}(h_e)$$

for a point inside the circle.

with A_{ji}, B_{ji}, C_{ji}; $j = 1,2$ depending on E_i

For a point outside the circle the formula is

$$X_i(o,o,o) = F \times \Big[(B_{1i} + B_{2i}\, h_e)\, (\sqrt{x_2} - \sqrt{x_1})$$

$$+ (C_{1i} + C_{2i}\, h_e)\, (x_2 - x_1) \Big] / \bar{u}(h_e)$$

<u>Plumerise formula (Stümke II)</u>

$$\Delta h = \frac{1{,}5 v_s d + 65\, d^{1{,}5}\, (\Delta T / T_s)^{0{,}25}}{\bar{u}(h_g)}$$

other formulas can be used.

Meteorological parameters

Diffusion parameters

$\sigma_y = A\,x^a \qquad \sigma_z = B\,x^b$

with A, a, B, b depending on the stability classes E_i

Horizontal windfield

subdivided into p wind speed classes ($p \leq 5$) and q wind direction categories ($q \leq 36$)

Windprofile

$$u(z_2) = u(z_1)\left(\frac{z_2}{z_1}\right)^{m_i}$$

m_i is a function of E_i

Stability classes

7 classes E_i. Six classes are defined by the stability parameter $S = \frac{\partial\theta/\partial z}{\bar{u}(69)^2}$ while the seventh one is linked to average wind speeds larger than 11.5m/s.

Discretisation for wind direction

Intervals of φ degrees are used ($\varphi \geq 10°$)

Mixing height

Freely chosen

Input data

Emission

Data for the point sources

- a reference number
- the geographical position in Belgian Lambert co-ordinates
- the geometrical height (m)
- the inner diameter of the orifice of the stack (m)
- the temperature of the effluents (°K)
- the total emission rate (Nm^3/s)
- the pollutant rate (kg/s)
- the height a.s.l. of the base of the chimney(m)

Data for the area sources

- geographical position of the centre of the circle in Belgian Lambert co-ordinates
- the mean height of the chimneys inside the circle (m)
- the radius of the circle(hm)
- the population density (inh/ha)
- the mean height a.s.l. of the area inside the circle (m)

Immission

Cumulative frequency distributions

Meteorology

For the pollution maps

- the mean wind speed of each class
- the wind direction factor (defines the number q of wind direction categories)
- the mixing height
- the values of m_i for the wind profile
- the discretisation angle ψ
- the height of the level of the measured values for wind speed
- the temperature

For the statistics

- a set of measured values of wind speed, wind direction, temperature and stability class (averages over a time t_{av}) over a period T

Program description

User's guide with complete description of the input data.
Maximum 200 point sources for one run.
The number of area sources is limited to 999.
The maximum number of grid points is 374 (17 x 22)
Individual chimneys can be subtracted or added.

Output

Numerical output or graphical display

List of symbols

$\chi_i(x,y,z)$	: average concentration of pollutant P_i at the point (x,y,z)
Q_i	: emission rate of pollutant P_i
$\delta^{-1}(x,y,z)$	: meteorological factor describing the atmospheric diffusion
$\bar{u}(z)$	: mean wind speed at height z
σ_y, σ_z	: horizontal and vertical diffusion parameters
h_e	: effective stack height
F	: correction factor comprising - the real population density - the physical temperature of the specified period
x_1	: crosswind distance between the receptor point and the nearest point of the circle (x_1 = 0 for a point inside the circle)
x_2	: crosswind distance between the receptor point and the farthest point of the circle
Δh	: plumerise ($= h_e - h_g$)
v_s	: exit velocity of the gases
d	: inner diameter of the orifice of the stack
ΔT	: $= T_s - T$
T_s	: temperature of the stack gas
T	: temperature of the ambient air
h_g	: geometrical stack height
$\partial\theta/\partial z$	: potential temperature gradient

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Christiansen, Porter; USA (TCM)

TEXAS CLIMATOLOGICAL MODEL (TCM)

Christiansen and Porter

1974

Abstract

The TCM is a long-term model which calculates concentrations of from one to three pollutants at up to 2500 locations in a uniform grid of arbitrary dimensions and spacing. Steady-state Gaussian plume point source logic is used, with crosswind distribution averaged across 22°5 azimuthal sectors. The dispersion equation is solved by interpolation in a table of precalculated coefficients rather than explicit calculation of the exponential terms. An extremely simple algorithm is employed to simulate area sources. Briggs plume rise is used. The 576-element meteorological joint frequency function input is simplified to 96 elements before concentrations are calculated. As a result of the efficiency measures outlined above, the TCM predicts essentially the same concentrations as the CDM, but is 80 to 400 times faster. In addition, the TCM is "self-calibrating", performing a first order least squares regression analysis on calculated vs. observed concentrations and applying the results to the calculated concentrations in the same run.

Basic Equations

Point Sources

For Source i,

$$\chi = (16\times10^6/2\pi) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi\,(k_i,\ell,m)\; Q_i S/x,$$

$$S = (2/\sqrt{2\pi}\, U_\ell \sigma_z)\exp\,(-H_i^2/2\sigma_z^2)\;\exp\,(-.692x/U_\ell T_{\frac{1}{2}})$$

(CDM; Busse and Zimmerman, 1973)

k_i = Wind sector appropriate to source i at receptor

ℓ = Wind speed class

m = Stability class

ϕ = Meteorological joint frequency function

U_ℓ = Central wind speed of class ℓ

x = Downwind distance

Define wind speed characteristic of entire stability class:

$$U_m = \left[\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi(k,\ell,m)\right] \left[\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi\,(k,\ell,m)/U_\ell\right]^{-1},$$

reduce $\phi\,(k,\ell,m)$ to $\phi(k,m)$.

Then

$$\chi = (16x10^6/2\pi) \sum_{m=1}^{6} \phi\ (k_i,m)\ Q_i S/x,$$

$$S = (2/\sqrt{2\pi}\ U_m \sigma_z)\ \exp\ (-H_i^2/2\sigma_z^2)\ \text{(decay term)}.$$

Let $K(x,H,m) = (32x10^6/2\pi)^{3/2} x\ \sigma_z)\ \exp\ (-H_i^2/2\sigma_z{}^2)$.

Finally,

$$\chi = Q_i \sum_{m=1}^{6} (K(x,H,m)\phi(k,m)/U_m)\ \text{(decay term)}.$$

K is precalculated for 1080 combinations of downwind distance (x), effective source height (H), and stability class (m). The dispersion equation is solved by interpolating for the correct K in data tables. Decay factors are also precalculated.

$$\sigma_z = ax^b,$$

a,b from Busse and Zimmerman (1973)

Plume Rise

$\Delta h = 1.6\ F^{1/3}\ (3.5x^*)^{2/3}$,

$x^* = 14F^{5/8}$ if $F < 55$,

$x^* = 34F^{2/5}$ if $F > 55$.

$F = gvr^2(T-T_{ambient})/T$,

(Briggs (1969))

Vertical Wind Profile

$U = U_o(z/z_o)^P$,

(Busse and Zimmerman (1973))

Area Sources

$\chi = FQ/U$,

Q = emission rate per unit area,

F = dimensionless constant, an input parameter

(Gifford and Hanna (1973))

Meteorological Input

Joint frequency function, ϕ (k,ℓ,m).

with

k = 16 22°.5 wind direction sectors

ℓ = 6 wind speed classes

m = 6 Turner stability classes:

A, B, C, D(day), D(night), E and F.

Other Meteorological Input: ambient temperature, decay half-lives of three pollutants.

Up to five joint frequency functions (96 cards each), along with five source inventories, may be input in each run. Usual application is four seasons plus annual.

Source Input

Area Sources = coordinates, size, emission rates.

Point Sources = coordinates, height, diameter, temperature, exit velocity, emission rates.

Output

Concentrations of one to three pollutants are calculated at up to 2500 locations in a uniform grid of arbitrary dimensions and spacing. The grid is the same one into which the area source emissions are apportioned-- concentrations are calculated at the center of each area source grid square.

Forms of output include list, map of concentrations across receptor grid, culpability list (5 highest contributing sources at each receptor), and punched cards.

Application

SO_2 and particulates for Houston, Dallas-Fort Worth, Corpus Christi, Austin, San Antonio, Beaumont-Port Arthur-Orange, USA; several smaller-scale applications.

Validation

SO_2 and particulates for Houston, Dallas-Fort Worth, New York City, USA.

Documentation

Complete users' manual.

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Christiansen; USA (TEM)

TEXAS EPISODIC MODEL (TEM)

Christiansen

1975

Abstract The TEM is a short-term model which calculates concentrations of one or two pollutants at up to 2500 locations in a uniform grid of arbitrary dimensions and spacing. Steady-state bivariate Gaussian plume point source logic is used, but the dispersion equation is solved by interpolation in tables of precalculated coefficients rather than explicit calculation of the exponential terms. This feature, along with an efficient algorithm for handling area sources, makes the TEM quite fast. Plume rise is calculated via six equations (all due to Briggs), the appropriate equation being chosen by the program on the basis of 1)downwind distance, 2)atmospheric stability, and 3)whether the rise of the plume is dominated by thermal buoyancy or momentum. Other features include treatment of exponential vertical wind profile, pollutant decay, conversion to different sampling times, and mixing height, including variable inversion penetrability. Several input and output options are available.

Basic Equations

Point Sources

$$\chi = \frac{10^6 Q}{\pi \sigma_y \sigma_z U} \exp(-y^2/2\sigma_y^2) \exp(-H^2/2\sigma_z^2 \exp(-.692x/UT_{\frac{1}{2}})$$

Substitute K_y and K_z:

$$K_y = \frac{1000}{\sigma_y} \exp\ (-y^2/2\sigma_y{}^2),$$

$$K_z = \frac{1000}{\pi\sigma_z} \exp\ (-H^2/2\sigma_z{}^2),$$

giving

$$\chi = \frac{K_y K_z Q}{U} \text{ (decay term)}$$

K_y and K_z are precalculated for 3080 combinations of downwind distance (x), crosswind angle ($\mathrm{Tan}^{-1} y/x$), effective source height (H), and stability class. The dispersion equation is solved by interpolating for the correct K_y and K_z in data tables. Decay factors are also precalculated.

$$\sigma_z = ax^b,$$

$$\sigma_y = cx^d,$$

a,b,c,d from Busse and Zimmerman (1973), Turner (1970).

	STABLE AIR	UNSTABLE AIR
BUOYANCY-DOMINATED	$\Delta h(x) = 1.6F^{1/3}\, x^{2/3} U^{-1}$ (5), or $\Delta h_{MAX} = 2.4[F/US]^{1/3}$ (6), where $S = 0.02g/T_A$, E stability, $S = 0.035g/T_A$, F stability.	$\Delta h(x) = 1.6F^{1/3}\, x^{2/3} U^{-1}$ (5) for $x < 3.5x^*$, or $\Delta h_{MAX} = 1.6F^{1/3}(3.5x^*)^{2/3} U^{-1}$ (7), for $x > 3.5x^*$. $x^* = 14F^{5/8}$ if $F < 55$, $x^* = 34F^{2/5}$ if $F > 55$.
MOMENTUM-DOMINATED	$\Delta h_{MAX} = 1.5(VR)^{2/3} U^{-1/3} S^{-1/6}$ (8), S as above.	$\Delta h(x) = 3.78\left(\frac{V^2}{U(V+3U)}\right)^{2/3}\left(\frac{xR^2}{2}\right)^{1/3}$ (9), or $\Delta h_{MAX} = 3VD/U$ (10).

$F = gVR^2(T-T_A)/T$.

T = source temperature, °K.

T_A = ambient temperature, °K.

V = velocity, m/s.

R = radius, m.

D = diameter, m.

x = downwind distance, m.

U = wind speed at physical source height, m/s.

g = acceleration due to gravity, 9.8 m/s^2.

All equations are due to Briggs (1969). Momentum or buoyancy dominance is determined from source parameters and ambient temperature.

Mixing Height

Turner (1970) treatment:

$$\chi = \frac{10^6 Q}{\sqrt{2\pi}\sigma_y LU} \exp\left(-y^2/2\sigma_y^2\right),$$

or $K_z \simeq 398L$

for total vertical mixing below mixing height L. At $x > 2x_m$, x_m = distance such that $\sigma_z = 0.47L$, equation above is used. For $x_m < x \leq 2\,x_m$, interpolation between equation above and original point source equation is employed.

Inversion penetration factor, I, is a program input for each weather scenario. If $H > LI$, plume escapes the mixing layer. If $L < H \leq LI$, plume does not escape, and H is set equal to L. Typically, $I \simeq 2$

Vertical Wind Profile

$$U = U_o\,(z/z_o)^P,$$

from Busse and Zimmerman (1973).

Area Sources

Area sources are input as squares of arbitrary size and location. They are reapportioned by the program to a uniform grid of squares. Each square is affected by diffuse emissions locally and in the N squares directly upwind:

$$X = \sqrt{\frac{2}{\pi}} \frac{(\Delta x/2)^{1-b}}{U_o a(1-b)} \left\{ Q_o + \sum_{i=1}^{N} Qi \left[(2i+1)^{1-b} - (2i-1)^{1-b} \right] \right\}$$

(Gifford and Hanna (1970)). In the TEM, N=4. For each wind direction, every area source square lays down the same concentration pattern, scaled by Q. There are 10 possible patterns, stored as data in the model.

Meteorological Input

Stability Classes: A, B, C, D (day, D (night), E, F (Turner).

Wind Speeds: any

Wind Directions: any

Other Meteorological Input: mixing height, inversion penetrability factor, ambient temperature, decay half-lives of two pollutants.
Up to eight distinct weather scenarios (with different values for any or all of the above meteorological parameters) may be used in one run of TEM. An option allows four or sixteen preselected wind directions to be simulated in each of the eight scenarios.

Source Input

Area Sources: coordinates, size, emission rates.
Point Sources: coordinates, height, diameter, temperature exit velocity, emission rates and identification.

Output

Concentrations of one or two pollutants are calculated at up to 2500 locations in a uniform grid of arbitrary dimensions and spacing. The grid is the same one into which the area source emissions are reapportioned--concentrations are calculated at the center of each area source grid square.

Forms of output include list, map of concentrations across receptor grid, culpability list (5 highest contributing sources at each receptor), and punched cards.

Application

SO_2 and particulates for Houston and Dallas-Fort Worth, USA and scores of smaller scale applications.

Frequency Distributions (Post-processor: Porter and Christiansen)

Frequency distributions of concentrations at a large number of receptors (up to 100) may be calculated using the TEM and a pre- and post-processor whose operation is transparent to the TEM itself. The pre-processor converts an input meteorological joint frequency function to a 576-element form, with 16 wind sectors, 6 wind speed classes, and 6 stability classes (A, B, C, D(day), D(night), E and F). This form is used directly by the Texas Climatological Model (TCM), a long-term companion to the TEM. The 576-element form is then converted to weather scenarios, with wind directions at the centers of the wind sectors, and wind speeds equal to the geometric mean of the wind speed class limits. The 16 wind direction per scenario option is used so six runs with six scenarios each are required. This amounts to sampling the joint frequency function at 16 specific wind directions, since crosswind concentration distributions are explicitly calculated, rather than integrated across each wind sector.

The post-processor stores concentrations for each scenario. When all TEM runs are complete, the post-processor applies the frequencies of occurrence of each scenario and calculates the critical parameters of the concentration frequency distribution at each receptor.

Documentation

Complete users' manual.

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Gifford, Hanna; USA (ATDL)

ATDL's urban area-source model

Authors:

Gifford and Hanna (1970)
Hanna (1971)
Gifford and Hanna (1973)
Hanna (1973a, b, and c)

Abstract:

The model calculates surface-level air pollution concentrations distribution over an urban area, given the area source strength distribution and values of the usual meteorological parameters. The model has been applied over various averaging times, from an hour to a year. Strong, isolated, elevated point sources are incorporated, where necessary, by a separate, standard plume calculation. Methods for accounting for dry and wet deposition and chemical reactions are provided.

Model characteristics:

a) assumes ground reflection
b) incorporates a vertical wind profile
c) incorporates vertically varying diffusivity
d) employs an area-source solution
e) uses Briggs' plume-rise calculation where necessary.
f) considers chemical reactions
g) considers half-life decay and/or deposition.

Results

There are two model versions:

1. The simplest version is a direct area-source solution in which the area source-strength pattern is assumed to be effectively constant over a central, usually 4x4 km grid.
2. In a more complex version the, entire area source grid enters the calculation.

Applications

Summarized in Table 1 from Report No. ATDL/78 (4th Meeting of NATO/CCM Panel on Modeling).

Basic Surface-Level Area-Source Solutions:

Version 1

$$X_{Ao} = C\, Q_o/u$$

where

$$C = (2/\pi)^{1/2}\, x^{1-b}\, [a(1-b)]^{-1}$$

Table 1

Comparison of Simple ATDL Urban Pollution Model With Various Other Models

City	Concentration value modelled	Period	Pollutant	Correlation Coefficient		Model
				ATDL	Other	
Chicago	Point	24 hr (for 18 days)	SO_2	.67	.69	Roberts, et al.
Chicago	Point	6 hr (for 4 days)	SO_2	.66	.80	"
Memphis	Area Pattern	Annual	Particle	.68	.73	AQDM
Nashville	"	"	"	.91	.80	"
Ankara	"	Seasonal	"	.63	.59	CDM
Bremen	"	"	SO_2	.65	.05	Fortak
"Test City"	"	Annual	Particle	.98	.96	AQDM
L.A.	Point	1 hr (for 17 hrs)	CO	.89	.48	PICK
San Francisco	"	1 hr (for 48 hrs)	"	.74	.66	McCracken et al.
L.A.	Area Average	1 hr (for 7 hrs)	NO	.97	.91	PICK
"	"	"	NO_2	.05	-.42	"
"	"	"	Reactive Hydrocarbons	.61	.55	"
London	"	24 hr avg.	SO_2	.76	.87	Met. Office

Version 2

$$\chi_{Ao} = (2/\pi)^{1/2} \frac{(\Delta x/2)^{1-b}}{a(1-b)u} \{Q_o + \sum_{i=1}^{N} Q_i[(2i+1)^{1-b} - (2i-1)^{1-b}]\}$$

a, b defined by

$$\sigma_z = ax^b \quad ;$$

u, the mean transport wind speed, is that given by representative wind observations in the source area.

Plume rise formula

Briggs' (1969) transitional rise formula is used.

Plume diffusion formula

The standard gaussian plume formula is used for large, isolated, elevated sources ($h \geq 40$ m in the Frankfort comparison). All others are lumped with the area source.

Diffusion parameter

$\sigma_z = ax^b$, a and b are functions of stability as defined in Ref. (1).

Mean transport wind

It is assumed that u equals the value, averaged over the given period, of the most representative wind observation for the area.

Wind direction

Method 1 does not depend upon wind direction. A 16 point wind rose is used in Method 2.

Vertical wind profile

As shown in the theoretical derivation in Ref. (1), it is the average wind speed and not the exact form of the vertical variation of the wind that is important in urban diffusion calculations.

Input Data: Emissions

1. Point sources: stack height, buoyancy flux, source strength.

2. Area sources: mean source strength within a grid square.

Meteorology

Method 1: Average wind speed and stability class.

Method 2: Average wind speed and stability class, 16 point wind rose.

Program Description:

Method 1: Hand calculation
Method 2: Program listing in Ref (4).

Literature:

(1) Gifford, F. A. and Hanna, S. R., 1970: Urban air pollution modeling, Proceedings of Second Int. Clean Air Cong. (H. M. England and W. T. Beery, eds.), Academic Press, New York, 1146-1151.

(2) Hanna, S. R., 1971: Simple methods of calculating dispersion from urban area sources. J. Air Poll. Control Assoc, 21, 774-777.

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(5) Hanna, S. R., 1973: A simple model for the analysis of chemically reactive pollutants. Atmos. Environ., 7, 803-817.

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Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Bresser, Kropp, Schneider;
Fed. Rep. of Germany

Model for the Immission Prognosis of Gaseous Pollutants

Developed at the Technischer Überwachungsverein Rheinland 1975

Summary

The present immission climatology model can be used for the immission prognosis of gaseous pollutants from point or area sources.

For given wind direction, wind speed and diffusion category the expected immission concentration at the grid points can be determined for short-term projections.

For long-term projections the frequency distribution of the immission concentration per annum, the mean values and the 90 - 99 percent values of the sum frequencies (90 - 99 percentiles) can be determined.

Characteristics

Decompositon of the area sources into point sources depending upon the distance to the first grid point.

Taking into consideration up to 10 different operating situations (times) of the sources. Dividing the wind direction categories into maximum 10 subcategories in which a homogeneous distribution of the wind direction is assumed.

Results

For short-term prognosis: output of the sum of concentrations for each grid point, for all wind direction categories to be evaluated, for all diffusion classes and all wind speed steps when all sources are under operation.

For long-term prognosis: Output of the frequency distributions of the immission concentrations per annum as sum frequencies of exceeded or not exceeded concentrations as well as of the mean values. Output of the portions of the different sources to the mean values at each grid point.

Output of the 90 - 99 percentile (sum frequencies of not exceeded concentration). Output of the averaged concentrations over single or all grid points as well as of the resulting 90 - 99 percentiles.

Applications

SO_2, NO_X, CO concentrations, as well as concentrations of other pollutants in cities of Nordrhein-Westfalen, esp. in Köln.

Basic Equation

For time constant point emissions is:

$$c\,(x,y,z) = \frac{Q}{2\pi\,\sigma_y\,\sigma_z\,u} \cdot \exp\left(-\frac{y^2}{2\,\sigma_y^2}\right) \cdot \left\{\exp\left(-\frac{(z-h)^2}{2\,\sigma_z^2}\right) + \exp\left(-\frac{(z+h)^2}{2\,\sigma_z^2}\right)\right\} \qquad (1)$$

Emissions from area sources are adapted to the equation by decomposition into point sources. The degree of the decomposition depends on the distance between the next grid point and the central point of the area source.

Plume Rise

Plume rise following Moses + Carson's formula for neutral conditions. The effective source height h (= height of the source + plume rise) results from the following equation:

$$h^{1+m} = H^{1+m} + \frac{z^m \cdot (1+m)}{UZ} \cdot (0.4 \cdot F_1^{1/2} + 28.1 \cdot F_2^{1/2}) \quad (2)$$

with

$$F_1 = \frac{QH \cdot (TH+273) \cdot VS}{273} \quad (3)$$

$$F_2 = \frac{9.81 \cdot QH \cdot (TH - TL)}{3.14 \cdot 273} \quad (4)$$

and $F_2 = 0$ for $TH < 30$ °C

Explanation of the terms:

H = height of the source in meters / m /
QH = amount of the exhaust gas / Nm^3/s /
TH = temperature of the exhaust gas / °C /
VS = exit speed / m/s /
TL = mean temperature of the ambient air / °C /
z = reference height / m /
UZ = wind speed at reference height / m/s /
m = exponent of wind speed profile, depending on turbulence categorie (A_k):

stable ⟶ unstable

A_k	2	3	4	5
m	0,4	0,28	0,22	0,11

Meteorological Parameters

Diffusion Parameters

The following parameters are used:

$$\sigma_y = (F \cdot x + F_o)^f \qquad \sigma_z = (G \cdot x + G_o)^g \qquad (5)$$

The coefficients F, F_o, f, G, G_o, and g depend upon the source height H and the distance x.

They are compiled in the following three tables:

a)

A_k	F	F_o	f	G	G_o	g	
2	0,38	0	0,90	0,24	0	0,92	unstable
3	0,31	0	0,85	0,19	0	0,80	↓
4	0,24	0	0,77	0,18	0	0,69	
5	0,21	0	0,77	0,07	0	0,68	stable

b)

A_k	F	F_o	f	G	G_o	g	
2	0,94	168	0,76	0,08	12	1,28	unstable
3	0,82	198	0,74	0,09	12	1,11	↓
4	1,19	354	0,67	0,60	42	0,74	
5	0,25	194	0,72	0,69	48	0,59	stable

c)

A_k	F	F_o	f	G	G_o	g	
2	1,22	0	0,76	0,10	0	1,28	unstable
3	1,15	0	0,74	0,11	0	1,11	↓
4	1,78	0	0,67	0,67	0	0,74	
5	0,54	0	0,72	0,77	0	0,59	stable

For distances $x \leq 600$ m and source heights $H \leq 20$ m the coefficients result from table b. For source heights 20 m $\leq H \leq$ 50 m

one has to interpolate linearly between the coefficients listed in tables b and c. For source heights between 50 and 100 m and for all distances one has to interpolate linearly between the coefficients listed in the tables a and c.

The coefficients for source heights $H > 100$ m are listed in table a.

Besides the above parameters the following parameter sets can be used in the program:

a) diffusion parameters of Klug
b) diffusion parameters of Pasquill
c) diffusion parameters of Fortak
d) diffusion parameters of Vogt.

Horizontal Wind Field

Wind direction classes of 10° are inserted generally. Category classifications of larger sectors may be used as well when lesser accuracies can be accepted.

The different wind directions are divided into up to 10 sub-sectors while the wind is assumed to be homogeneously into these sub-sectors.

Thus a more homogeneous spatial immission distribution is obtained. The wind speeds are divided into 10 categories.

Vertical Wind Speed Profile

$$u = \frac{UZ}{m+1} \cdot \left(\frac{h}{z}\right)^m \qquad \text{for } h > 10 \text{ m} \qquad (6)$$

$$u = \frac{UZ}{m+1} \cdot \left(\frac{10}{z}\right)^m \qquad \text{for } h \leq 10 \text{ m} \qquad (7)$$

The exponents m are the same as indicated for the plume rise.

Diffusion Categories

The diffusion categories may be attributed arbitrarily to the parameter sets.

Generally correspond:

Categories following Turner
-parameters following Fortak or indicated tables

Categories following Klug/Manier
-parameters following Klug or Vogt

Categories following Pasquill
-parameters following Pasquill.

Input Data

Emission Data

emission of pollutants	/ kg/h /
amount of exhaust gas	/ Nm^3/h /
exhaust gas temperature	/ °C /
exit speed	/ m/s /
source height	/ m /

Meteorology

Joint frequency distribution of wind direction, wind speed and diffusion categories.

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Braig, Strott; Fed. Rep. of Germany
(revised ATDL)

NATO/CCMS

AIR POLLUTION PILOT STUDY

ASSESSMENT METHODOLOGY AND

MODELING

MODELING PANEL

Brief Description of the

Revised ATDL-Model

by

BATTELLE - INSTITUT E.V.

Annex to

Techn. Doc. M.P. 1/1977 3.4

Principles of Multiple Source

Urban Air Quality Modeling

Authors

Hanna, Gifford

(revised by Battelle-Institut e.V.)

Abstract

The multiple source urban diffusion model calculates annual averages and 95 percent values for different pollutants.

The model is based on the following characteristics:

a) use of a vertical wind profile

b) point sources are situated at the midpoints of the grid produced by the area sources

c) point sources are classified according to their effective source height

d) receptors are identical with the midpoints of the grid.

Results

The model calculates immission values for each receptor of the grid. The parts of the point and area sources can be calculated separately.

The results include

- annual averages
- 95 percent value of the cumulative frequency distribution
- 4 x 4 km value according to the "TALuft"

Application

SO_2 concentration in Frankfurt/Main

Basic Equations

Point Sources

$$\chi = Q \cdot \left\{ \frac{\exp\left[- \frac{y^2}{2\sigma_y^2} \right]}{\sqrt{2\pi} \cdot \sigma_y} \right\} \cdot S$$

$$S = \frac{1}{\sqrt{2\pi} u \sigma_z(x)} \left\{ \exp\left[- \frac{(z-h)^2}{2\sigma_z^2} \right] + \exp\left[- \frac{(z+h)^2}{2\sigma_z^2} \right] \right\}$$

By assuming a narrow plume we find:

$$\chi(x) = \frac{16}{2\pi} \sqrt{\frac{2}{\pi}} \frac{Q}{u\sigma_z \cdot x} \exp\left[- \frac{h^2}{2\sigma_z^2} \right]$$

Area Sources

According to the line source concept of Gifford each area source in simulated by a cross-wind line source. The grounde level concentration is the sum of the parts χ_K of the area sources situated upwind

$$\chi_K = \frac{Q_K}{u\sqrt{2\pi}} \int_{x_u}^{x_o} F(x, h)dx = Q_K I_K/(u\sqrt{2\pi})$$

$$F(x, h) = \exp\left\{ - h^2/2\sigma_z^2 \right\} / \sigma_z$$

x_u, x_o = lower and upper distance of an upwind area source

The integrals with $k > o$ are approximated:

$$I_K = F(x, h) \cdot \Delta x \quad \text{with } x = (x_o + x_u)/2$$

The Integral I_o is calculated numerically.

Plume Rise Formula

$\Delta h = 1.6\ F^{1/3}\ (3.5x^*)^{2/3}/u$ for $x > 3.5x^*$

$\Delta h = 1.6\ F^{1/3}\ x^{2/3}/u$ for $x \leq 3.5x^*$

with $x^* = 14\ F^{5/8}$ if $F \leq 55$

$x^* = 34\ F^{2/5}$ if $F > 55$

and $F = g \cdot v_s \cdot 0.25 \cdot d^2 \cdot \Delta T/T_s$

where: d inside stack diameter of the mouth

v_s exit velocity of the stack gas

T_s temperature of the stack gas

$\Delta T = T_s - 283K$

Meteorological Parameters

Diffusion Parameters

$$\sigma_z(x) = ax^b$$

a, b according to Pasquill.

stability class	Diffusion parameters a	b
I	o.11727	o.67
II	o.14856	o.73
III_1	o.19943	o.76
III_2	o.22294	o.8o
IV	o.22547	o.85
V	o.27934	o.9o

Stability Class

Klug: I - VI
(stable) (unstable)

Horizontal Wind Field

wind speed: 6 velocity-classes (kts):

o-2; 3-5; 6-8; 9-12; 13-17; 18-3o;

means velocities (m):
1; 2.1; 3.6; 5.3; 7.5; 1o.2

wind direction: 16 sectors

Vertical Wind Profile

$$u(z) = u(z_o)(z/z_o)^m$$

with stability-dependent exponent m:

stability class	I	II	III_1	III_2	IV	V
m	o.4	o.4	o.28	o.22	o.1	o.1

Inversion Height:

Inversion height is not considered in the model.

Input Data

Emission

Complete emission inventory for point and area sources.
For singular emittents:

- source strength (Q)
- physical stack height (H)
- stack diameter (d)
- vertical velocity of the stack gas (v_s)
- temperature of the stack gas (T_s)
- source coordinates

For area sources:

- mean source strenght within the grid
- source height (= mean building height)

(only area sources of 1 km x 1 km are possible)

Meteorology

Three parametric (joint) frequency distribution of wind direction, wind speed, and stability class (10° sectors are internally transformed to 22.5° sectors).

Program Description

User's Manual with complete program des ription. Input orders and listings are available. The restrictions implied in the program, such as number of sources etc. can easily be modified.

Literature

Gifford, F.A. jun; Hanna, S.R.:
Urban Air Pollution Modeling
Proc. 2nd Int. Clean Air Congress
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Battelle-reports:
Vergleich von Rechenmodellen zur Ausbreitungsrechnung, parts 1-4
Reports for the German Ministry of the Interior

Technical Data of the Revised ATDL Model

Storage

There are about 13.000 words required for program and data fields.

Program

The programm consists of 470 cards, punched in EBCDIC code.

Time

The required time depends on the number of receptors.

In the case of 100 sources the CPU-time required for one receptor (Burroughs B6700) is about 4.3 sec.

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Braig, Strott; Fed. Rep. of Germany
(revised CDM)

Long-Term Models

2.1.1 CLIMATOLOGICAL DISPERSION MODEL (CDM)

Calder (Battelle-Version)
(long-term model)
1971

Abstract

A long-term model for calculation of annual averages of ground level concentrations for different pollutants (SO_2, CO). Uses point and area sources. May be used also for seasons, e. g. heating period.
Characteristic for the model is:

a) simulation of area sources (see basic equation)

b) plumerise formula (Briggs)

c) use of a vertical wind profile

d) consideration of chemical reduction (half-life)

Results

For each grid point of the area under consideration the ground level concentration is calculated and differentiated after point and area source parts (annual mean, periodical mean)

Application

SO_2 concentration in Ankara /Turkey, St. Louis /USA and New York /USA

Basic equations

Point and area sources (continuously)

$$\chi = Q \left\{ \frac{\exp\left[-\frac{y^2}{2\sigma_y^2}\right]}{\sqrt{2\pi}\,\sigma_y} \right\} \cdot S \quad e^{-0.693 x/\bar{u}\tau}$$

(the bracket approximated by use of a narrow-plume-assumption)

with

$$S = \frac{1}{\sqrt{2\pi}\,\bar{u}\,\sigma_z(x)} \left\{ \exp\left[-\frac{(z-h)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+h)^2}{2\sigma_z^2}\right] \right\}$$

Point sources (N=number of sources)

$$\bar{\chi}_p = \frac{16}{2\pi} \sum_{n=1}^{N} \sum_{W} \sum_{ST} F(h, W, ST)\ \chi_n(\tau, W, ST)$$

(formula is identical with the ACDM-version)

Area sources

$$\bar{\chi}_A = \frac{16}{2\pi} \int_0^{\infty} \left\{ \sum_{k=1}^{16} q_k(\tau) \sum_{W} \sum_{ST} F(h, W, ST)\ S(\tau, h, ST) \right\} d\tau$$

with

$$q_k(\tau) = \int_{k\text{-sector}} Q(\tau, \varphi)\ d\varphi.$$

The integrations is done numerically by subdividing the 22.5 sector in sector elements

For $x > 2x_L$ $\quad (x_L : \sigma_z(x_L) = 0.47\,L)$

$$S = \frac{1}{u\,L} \exp\left[-0.629\,\tau/u\tau\right].$$

<u>Plumrise formula</u>

$\Delta h = 1.6\,F^{1/3}\,(3.5x^*)^{2/3}/u$ for $x > 3.5\,x^*$

$\Delta h = 1.6\,F^{1/3}\,x^{2/3}/u$ for $x \leq 3.5\,x^*$

with $x^* = 14\,F^{5/8}$ if $F \leq 55$

$x^* = 34\ F^{2/5}$ if $F > 55$

$F = g\ v_s \cdot 0.25\ d^2 \cdot \Delta T/T_s$

(BRIGGS 1971),

application only for singular emittents

Meteorological parameters

Diffusion parameter

$\sigma(x) = ax^b + c$

a, b, c, after Pasquill

For $x > 2\ x_L$: $\sigma_z = 0.8\ L$

$\sigma_{zo} = 30$ m (roughness of topography)

Horizontal wind field

Simulated by using 22.5^0 sectors for the wind rose, subdivision into 6 wind speed classes

Wind profile

$$u = u_o\left(\frac{z}{z_o}\right)^m$$

m = m (stability class)

Stability class

Turner classes: A - F (6)

(unstable - stable)

Mixing height

L = L (ST); L (ST) = f (HT, HMIN)

For area sources a city climate is considered by:

L(ST) = L (ST - 1)

Input data

Emission

Complete emission inventory for point and area sources (source strenght, area size), additional stack data (v, d, H, T) for singular emittents.

v = speed of emission

d = stack diameter

H = physical stack height

T = temperature

Immission

Regression coefficients a, b (are to be got experimentally by an earlier computer run) for the line

$$\chi_{observed} = a \ \chi_{calculated} + b$$

Meteorology

Three parametric (joint) frequency distribution of wind direction, wind speed and stability class, i.e. (16 x 6 x 6 = 576 values), mean mixing height in the afternoon (HT) and at night (HMIN), mean wind speed per stability class.

Program description

User's Manual with full program description and input orders. Emission inventory: max. 2500 area sources, max. 200 point sources. The number of receptor points is unlimited.

Output in table or in cards
for later PLOT programs
optionally.

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Gutsche, Stern; Fed. Rep. of Germany

NATO / CCMS
AIR POLLUTION PILOT STUDY
ASSESSMENT METHODOLOGY AND MODELING

MODELING PANEL

Brief Description of Fortak's multiple source urban diffusion model

by

B. GUTSCHE and R. STERN

Annex to
Techn. Doc. M. P. 1/1977 3.4

Principles of Multiple Source Urban
Air Quality Modeling

FORTAK's multiple-source urban diffusion model

Author: FORTAK
(long-term model)
1966, 1970

Abstract: The model calculates annual averages and cumulative frequency distributions of ground-level concentrations for different pollutants as an immission climatological basis for regional planning activities. It uses point sources and an algorithm for a comprehensive description of area sources.

Characteristic for the model is:

a) total reflection boundary conditions at the earth's surface and in the inversion height;

b) by choice: consideration of chemical reaction (half-life) and absorption at the earth's surface

c) use of a vertical wind-profile

d) vertical differentiation of dispersion parameters

e) simulation of area sources

f) plume rise formula:

Stümke (1963) for singular point sources, empirical relations for area sources.

Results

two model versions:

1. a source-orientated version calculates annual averages and frequency distributions for prescribed grid-points (45 x 45 grid-points with a mesh size of 500 by 500 meters)
2. a receptor-orientated version calculates annual averages and frequency distributions for an optional number of receptor points with arbitrary position; thus, reducing computation time and facilitating validation of the model, if the position of the calculation point is identical with that of the measuring site.

Application

SO_2-concentration in Bremen, Düsseldorf, Frankfurt, Berlin (all in Germany)

Basic equations

Point sources

a) without inversion;
total reflection condition at the earth's surface

$$\chi = \frac{Q}{U} \exp(-\gamma\tau) \frac{\exp\left[-\frac{y^2}{2\sigma_y^2}\right]}{\sqrt{2\pi}\,\sigma_y} \cdot S$$

$$S = \frac{1}{\sqrt{2\pi}\,\sigma_z}\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\}$$

b) total reflection condition at the earth's surface as well as at an inversion in height H_I:

$$\chi = \frac{Q}{2\,H_I\,\bar{u}} \exp(-\gamma\tau)\,\frac{\exp\left[\frac{-y^2}{2\sigma_y^2}\right]}{\sqrt{2\pi}\,\sigma_y} \times$$

$$\times \left\{ \theta_3\left(\frac{z-H}{2\,H_I};\frac{\sigma_z^2}{2H_I^2}\right) + \theta_3\left(\frac{z+H}{2H_I};\frac{\sigma_z^2}{2H_I^2}\right)\right\}$$

$$\theta_3\,(V;\,W) = \frac{1}{\sqrt{\pi\,W}} \sum_{n=-\infty}^{+\infty} \exp\left[-\frac{(V+n)^2}{W}\right]$$

c) the mean transport velocity is in a) as well as in b) is determined as

$$\bar{u} = \frac{1}{2\,H}\int_0^{2H} u\,(z)\,dz$$

H being the effective stack height

<u>Area sources</u>

The area source is simulated by 100 identical singular point sources distributed uniformly over the grid square. The contribution of these sources to the ground-level concentration field is calculated with the same basic equations as above.

<u>Plume rise Formula</u>

for singular emittents: Stümke (1963)

$$\Delta h = \frac{1}{\bar{u}_1}\left\{1{,}5\,v_s\,d_s + 65\,d_s^{3/2}\left(\frac{\Delta T}{T_s}\right)^{1/4}\right\}$$

$$\bar{u}_1 = \frac{1}{\Delta h} \cdot \int_h^{h+\Delta h} u(z)\,dz\,;$$ h: physical stack heigh

d_s : inside stack diameter at the mouth,

v_s : exit velocity of the stack gas

T_s(K): temperature of the stack gas

$\Delta T = T_s - 283$ K

for area sources: stability-dependent empirical relations

TURNER class	2	3	4	5	6	
$\bar{u}_1 \cdot \Delta h$	25	21	19	17	11	m^2/s

Meteorological Parameters:

Diffusion parameters

$$\sigma_y = F x^f \; ; \; \sigma_z = G x^g$$

parameters F, f, G, g

- after McElroy and Pooler (1968) for effective stack heights less then 40 m (Table 1)
- after Singer and Smith (1966) (modified) for effective stack heights greater than 40 m (Table 2)

Stability class

Turner classes (1964): 2 (unstable) - 6 (stable)

Horizontal wind field

wind speed: - 6 classes; the choice of the classes and of the representative wind speed for each class depends on the local frequency distribution of wind speeds (e.g. Table 3 for Frankfurt)

- the range of applicability of the basic equations excludes meteorological situations with wind speeds less than 1 m/sec.

wind direction: 10° - sectors; for model calculations a subdivision in 2°-sectors under the assumption of uniform distribution within the corresponding 10°-sector

Vertical wind profile

$$u(z) = u(z_o)\left(\frac{z}{z_o}\right)^m$$

with stability-dependent exponent m

TURNER class	2	3	4	5	6
m	0.111	0.208	0.288	0.396	0.419

Input Data

Emission

Complete emission inventory for point and area sources:

for singular emittents:
- source strength
- physical stack height
- stack diameter
- vertical velocity of the stack gas
- temperature of the stack gas

for area sources:
- mean source strenght within a grid-square
- mean building height in a grid-square

Immis on

Only if a fetch from large industrial areas far outside the model boundaries shall be considered

Meteorology

Three parametric (joint) frequency distribution of wind direction, wind speed, and stability class, i.e. 36 x 6 x 6 = 1296 situations, which, however, do not all occur.

Mean inversion height from the radio-sonde station nearest to the region under consideration.

Program description

Theoretical description of the GAUSSian plume model in GUTSCHE, LENSCHOW (1973); user's manual with full program description and input orders in STERN (1975)

Literature:

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contribution to the Practical Demonstration of Urban Air Quality Simulation Models within the NATO /CCMS Pilot Study Air Pollution,
Berlin 1977

TURNER class	F	f	G	g
2	1.21	0.76	0.05	1.28
3	0.86	0.77	0.09	1.10
4	1.25	0.69	0.72	0.74
5, 6	0.57	0.73	0.83	0.59

Table 1: Coefficients of the diffusion parameters after McElroy and Pooler for effective stack heights $\leq$ 40 m

TURNER class	F	f	G	g
2	0.40	0.91	0.28	0.92
3	0.36	0.86	0.26	0.80
4	0.32	0.78	0.30	0.69
5, 6	0.31	0.71	0.15	0.64

Table 2: Coefficients of the diffusion parameters after Singer and Smith (modified) for effective stack heights $>$ 40 m

class	u (knots)	$\bar{u}$ (m/s)
1	$\leq$ 2	0.5 (class 1 being excluded)
2	3 - 5	2.0
3	6 - 9	4.0
4	10 - 14	6.0
5	15 - 20	9.0
6	$\geq$ 21	12.0

Table 3: Wind speed classification for Frankfurt determined from data for 1967 - 1972

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Description
of

Calder; USA

NATO/CCMS PANEL N MODELING

Documentation for Practical Demonstration

of Urban Air Quality Simulation Models

MULTIPLE-SOURCE PLUME MODELS FOR URBAN AIR POLLUTION

- THEIR GENERAL STRUCTURE -

by

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* This paper is one of a trilogy prepared by the Meteorology and Assessment Division in support of documentation for the demonstration exercise. The other two complementary papers in the set are:

1. A Climatological Dispersion Model for 10° Wind Sectors (CDM 36): by D. B. Turner.
2. A Frequency-Distribution Algorithm for Multiple-Source Short-Term Pollution Concentrations: by John S. Irwin.

MULTIPLE-SOURCE PLUME MODELS OF URBAN AIR POLLUTION
-THEIR GENERAL STRUCTURE-

by

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Abstract

The general mathematical structure of the typical multiple-source plume model for estimating concentrations of an inert air pollutant in an urban area is examined. The fundamental component is the short-term three-dimensional spatial concentration distribution resulting from a single elevated point source. From this the total pollution pattern is obtained by superposition of the effects of the individual plumes of the many point- and area-sources that constitute the urban emissions. However, superposition of the effects is generally required for time-changing emissions and also meteorological conditions. The simplifying assumptions that are basic to the short-term plume model are identified, and the frequency distribution of concentration values at a receptor location, and the long-term average values are considered. Special consideration is given to the use of the well-known Gaussian-plume and its modification when the depth of the urban mixing layer is limited. As a typical point-source plume is normally narrow,

* On assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce

considerable simplification is possible i evaluating the concentration contribution from area-source emissions and this narrow plume approximation is described. When the emissions and the meteorological conditions affecting plume dispersion are uncorrelated, the average concentration can be calculated directly in terms of average emission rates and a frequency function for the meteorological conditions. The values so derived using the short-term multiple-source plume model are mathematically consistent with the formulation provided by an earlier long-term climatological model of urban air pollution.

I. Introduction

An attempt is made to examine in some detail the general formal structure of the typical multiple-source plume model (and especially the Gaussian-plume) that is in use at the present time for urban air quality simulation. In spite of the basic simplicity of the plume concept, the superposition of the concentrations of many plumes, as for an urban situation, and for a wide variety of meteorological and plume dispersal conditions, leads to considerable complexities of detail even at the present stage of model development. It therefore seems desirable to state the formal structure as unambiguously as possible, as a basis for further elaboration of the treatment (see also Calder (1969)). It is also hoped that by so-doing some possible misunderstandings may be removed, that seem to occur from time to time among the users of models. Some emphasis on basic structure has also seemed worthwhile as an antidote to the rather common abuse of the term "model" in air pollution circles. There are now so many acronym-named Gaussian-plume "models" available that questions could perhaps justifiably be raised as to the compatability of this multiplicity and reliability of performance. The actual situation is, of course, that most of these "models" are only special purpose computational algorithms and that the basic Gaussian-plume is the critical element that is common to all of them. Appreciation of this, and the fact that only relatively minor differences normally occur in the different formulations of this common element, may help to boost the confidence of the users of these models.

II. The Quasi-Steady State and Superposition

The starting point for the majority of urban air quality models is the assumption of a quasi-steady state. In spite of the obvious long-term variability of emissions, pollutant concentrations and of the meteorological conditions affecting transport and diffusion, it is assumed as a working approximation that this variability can be treated as though it resulted from a time-sequence of different steady-state situations. The sequence interval is normally taken to be relatively short, and perhaps only of the order of one hour. However, each interval is assumed sufficiently long to permit full development of the concentration fields at all locations, due to the individual sources. This could clearly be a poor approximation at low wind speeds for the concentrations in the "far-field" of an individual source, although still adequate for the "near-field" values. Nevertheless, the starting point for the general urban pollution model is a short-term steady-state model and the general non-steady state situation is then resolved into a sequence of "steady-state" intervals. In general, both the pollutant source distribution and the meteorological conditions must be regarded as varying between the consecutive periods of a time sequence $t_n (n=1, 2...N)$.

For pollutants that can be regarded as chemically inert it is further assumed that the concentration contributions produced at a receptor location from several sources combine additively. Without any loss of generality it

is possible to consider all cases of emission as subsumed mathematically by a volume distribution. We consider a fixed rectangular coordinate system with the plane $z = o$ at ground level, and also assume that the pollutant transport by the wind over the urban area can be characterized in terms of a single horizontal direction that makes an angle, say θ, with the positive x-axis of the coordinate system. We thus explicitly separate the "wind-direction" variable from all other meteorological variables that influence the transport and dispersion of pollution in the urban boundary layer, e.g., wind speed, atmospheric stability category, mixing depth, etc. These latter variables may be regarded as defining a meteorological-dispersion index $\nu(\nu = 1,2,\ldots)$ that will be a function of t_n, i.e., $\nu = \nu(t_n)$. The index number simply designates a given meteorological state out of the totality of possible combinations, i.e., a specified combination of wind speed, stability and mixing depth. Then from the additive property of concentration it follows that the total concentration $C(x,y,z;t_n)$ for the time interval t_n that results from the superposition of the concentration fields from the entire volume distribution can be written as a summation (actually representing a three-dimensional integral).

$$C(x,y,z;t_n) = \sum_{(\xi,\eta,\zeta)\in V} Q_v(\xi,\eta,\zeta;t_n)\, R\{x,y,z;\xi,\eta,\zeta;\theta_n,\nu(t_n)\}\,\Delta V \quad (1)$$

where $Q_v(\xi,\eta,\zeta;t_n)$ = steady emission rate per unit volume and unit time at position (ξ,η,ζ) for time interval $t = t_n$.

$R\{x, y, z; \xi, \eta, \zeta; \theta_n, \nu(t_n)\}$ = concentration at (x,y,z) produced by a steady point-source of unit strength located at (ξ, η, ζ), and for time interval t_n when $\theta = \theta_n$.

and the summation is taken over all the elemental source locations (ξ, η, ζ) of the entire volume distribution V. The function R is a meteorological-dispersion function that is explicitly dependent on the wind direction θ_n and implicitly dependent on the other meteorological variables that will be determined by the time-sequence t_n. In all simple urban models now in use the function R is taken to be a fixed, i.e., non-stochastic, function although its variables θ_n and $\nu(t_n)$ may be regarded as random variables. The general expression of the principle of superposition expressed by equation (1), and involving a dispersion function R that is a function of 6 independent spatial variables (4 horizontal ones) is more general than that assumed in most air quality simulation models. These normally assume that the dispersion function R is independent of the horizontal location of the source, so that R is invariant under arbitrary horizontal translations of the source-receptor pair. Although this can obviously only be an approximation in an average sense, in view of the rather inhomogeneous nature of the surface and the distribution of the buildings in a city, the variation of dispersion with source location may nevertheless be small in comparison with variations due to other causes, and the assumption is always made for purposes of simplification. It may be referred to as that of horizontal homogeneity of the

dispersion, and reduces R to a function of only two independent horizontal spatial variables, so that (1) may be rewritten as

$$C(x,y,z;t_n) = \sum_{(\xi,\eta,\zeta)\in V} Q_v(\xi,\eta,\zeta;t_n) R\{x-\xi, y-\eta; z,\zeta; \theta_n, \nu(t_n)\} \Delta V \qquad -(2)$$

It is convenient to introduce relative horizontal position coordinates, putting

$$\begin{aligned} x-\xi &= X \\ y-\eta &= Y \end{aligned} \qquad -(3)$$

Then (2) may be written

$$C(x,y,z;t_n) = \sum_{(X,Y,\zeta)\in V} Q_v(x-X, y-Y, \zeta; t_n) R\{X, Y; z,\zeta; \theta_n, \nu(t_n)\} \Delta V \qquad -(4)$$

and the summation extends over the entire source distribution. Finally, it is normally assumed that the dispersion function R only depends on θ through a simple rotation of horizontal axes transformation, and that it is independent of the "actual" value of the single horizontal wind direction that is assumed to characterize the pollutant transport over the urban area, provided the x-axis of the coordinate system is taken along this direction. If this is done then the dispersion function is directionally isotropic.

Denoting variables relative to the wind-oriented system by underbars, then

$$\begin{aligned} \underline{X} &= X\cos\theta + Y\sin\theta \\ \underline{Y} &= Y\cos\theta - X\sin\theta \\ X &= \underline{X}\cos\theta - \underline{Y}\sin\theta \\ Y &= \underline{Y}\cos\theta + \underline{X}\sin\theta \end{aligned} \qquad -(5)$$

and the isotropy property implies that

$$R\{X, Y; z, \xi; \theta_n, \nu(t_n)\} \equiv K\{\underline{X}, \underline{Y}; z, \xi; \nu(t_n)\} \qquad -(6)$$

where the (fixed)functional form K no longer involves θ explicitly and is thus independent of the actual direction of airflow over the city. The equations (4), (5), and (6) express the formal structure of most "short-term" multiple-source urban air quality models in use of the present time. All three quantities C( ), Q_v( ) and R{ } in equation (4) should be regarded as random variables, each with an <u>ensemble</u> corresponding to the sequential time values t_n(n = 1,2,...N). Although the function R{ } is assumed to be of fixed mathematical form it becomes a random variable because its own variables, i.e. θ_n and $\nu(t_n)$, have random distributions with t_n. Since time-sequential values of concentration can be calculated at an arbitrary receptor location, equation (4) is capable of providing a great deal of

information once the mathematical form of the dispersion function R has been specified. Thus the ensemble of C-values (say, one-hourly values) themselves possess a frequency distribution, or can be averaged over any longer period that is of interest, e.g., 3 hr, 24 hr, 1 yr, etc. More sophisticated statistical properties of the field of random concentration values could also be studied through use of equation (4), such as correlation or spectral properties. Many of these questions have so far received very little attention. In the following section we consider the concentration frequency distribution and average value for a fixed location.

III. Frequency Distribution of Concentrations and Average Value at Arbitrary Receptor Location

We first note that, if so desired, the summation in (4) over the total region V of the emissions could be broken down into mutually exclusive source subaggregations, say $V = V_1 + V_2 \ldots V_r$, so that

$$C(x,y,z;t_n) = \sum_r C_r(x,y,z;t_n) \qquad -(7)$$

where C_r denotes the concentration contribution due to the source aggregation V_r, and

$$C_r(x,y,z;t_n) = \sum_{(X,Y,\xi)\in V_r} Q_v(x-X,y-Y,\xi;t_n)R\{X,Y;z,\xi;\theta_n,\nu(t_n)\}\Delta V_r \qquad -(8)$$

This breakdown of the total concentration into contributions from specified source aggregations is sometimes important (and especially in terms of time-averaged concentration values) in comparing alternative air pollution control strategies and in cost-benefit studies. That such a breakdown is possible is, of course, an immediate consequence of the additivity property that was initially assumed for concentration.

Both C and C_r will have frequency distributions defined over their respective ensembles, and corresponding to the time sequence $t_n (n = 1,2,...N)$. For a 1-year set of hourly values this involves 365x24 values. If F(c) denotes the one-dimensional cumulative frequency (or probability) function so that

$$F(c) = \text{Prob}\{C \leq c\} \qquad (9)$$

then F(c) = M/N, where M is the number of cases for which $C(x,y,z;t_n) \leq c$ and N is the total number of cases. The key to economical computing of the frequency function is some appropriate technique of statistical sampling over the large number of points of the sampling space t_n, and this will be discussed later.

The (ensemble) average concentration (i.e., the so-called expected value of probability theory), which we denote by an overbar, is given by

$$\overline{C}(\underline{x},y,z) = \overline{C(x,y,z;t_n)} = \sum_{n=1}^{N} C(x,y,z;t_n)/N \qquad (10)$$

An important case arises here when the emission intensities Q_v and the dispersion functions R, i.e., the meteorological conditions, can be assumed to be independent or uncorrelated. This assumption is made in most air quality models. In this case the average value of the product of Q_v and R is equal to the product of their average values, and we thus have from (4) (since the order of averaging and the summation over the emissions distribution can be interchanged).

$$\overline{C}(x,y,z) = \sum_{(X,Y,\xi)\in V} \overline{Q}_v(x-X, y-Y, \xi)\overline{R}(X,Y;z,\xi)\Delta V \qquad -(11)$$

where $\overline{Q}_v$ denotes the time-average source strength and $\overline{R}$ the average value of the meteorological dispersion function. Thus if $f(\theta,\nu)$* denotes the joint-frequency function for wind direction θ and dispersion index ν, so that

$$\sum_{\theta}\sum_{\nu} f(\theta,\nu) = 1$$

then

$$\overline{R}(X,Y;z,\xi) = \sum_{\theta}\sum_{\nu} R\{X,Y;z,\xi;\theta,\nu\} f(\theta,\nu) \qquad -(12)$$

When this expression is substituted in equation (11) the order of the

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* Although for notational simplicity we have used a summation sign over θ, the wind direction variable θ is actually a continuous variable, although the dispersion index ν is normally assumed to be discrete and to take only a finite number of values. Thus $f(\theta,\nu)$ refers to a mixed continuous-discrete type of frequency distribution.

summations may, of course, be arbitrarily changed in any way that is desired. This allows consideration of many special problems. For example, if there were interest in the average concentration contribution at the receptor from a particular source aggregation V_r and a particular wind direction θ, say $C_{r,\theta}(x,y,z)$, then

$$\overline{C}_{r,\theta}(x,y,z) = \sum_{(X,Y,\xi)\in V_r} Q_v(x-X, y-Y, \xi) \sum_{\nu} R\{X,Y;z,\xi;\theta,\nu\} f(\theta,\nu)\Delta V_r \qquad -(13)$$

Then

$$\overline{C}(x,y,z) = \sum_{r}\sum_{\theta} \overline{C}_{r,\theta}(x,y,z) \qquad -(14)$$

It should be emphasized, however, that in the general case when emissions and meteorological conditions may be correlated (e.g., where the pollution results from space heating which will be more intense when temperatures are low as in the winter) it is necessary to use the general equation (4) and to obtain the average value using the frequency function F(c) of equation (9), i.e., through the simple integration (Stieltjes)

$$\overline{C}(x,y,z) = \int_0^\infty c\, dF(c) \qquad -(15)$$

However, without the consideration of special functions (not generally available) to convert information on time-averaged emissions to the short-term emission rates that are required in the basic equation (4), model calculations are frequently made using only time-average values of the emissions and assuming independence of the emissions and meteorology.

IV. Area- and Point-Source Emissions

In the preceding discussion, in terms of equation (1), of the formal structure of the short-term multiple-source air quality model, it was convenient to consider the ideal case of a general three-dimensional volume distribution of emissions, since this subsumes all other cases if we make use of the formal device of the Dirac delta function. We first rewrite (2) explicitly as a three-dimensional integral, namely

$$C(x,y,z;t_n) = \iiint_V Q_V(\xi,\eta,\zeta;t_n)\,R\{x-\xi,y-\eta;z,\zeta;\theta_n,\nu(t_n)\}\,d\xi\,d\eta\,d\zeta \qquad -(16)$$

Then by this procedure the general volume distribution may be considered as including the point-sources and the horizontal area-sources that are more normally considered in urban air quality simulation models. Thus, for an extended horizontal area-source, located at height $\zeta = \zeta_s$ and of strength $Q_A(\xi,\eta,\zeta_s;t_n)$ per unit area and per unit time, for $t = t_n$

$$Q_V(\xi,\eta,\zeta;t_n) = Q_A(\xi,\eta,\zeta_s;t_n)\,\delta(\zeta-\zeta_s) \qquad -(17)$$

so that equation (16) then gives (from the sifting property of the δ-function when under the integral sign)

$$C(x,y,z;t_n) = \iint_A Q_A(\xi,\eta,\zeta_s;t_n)\,R\{x-\xi,y-\eta;z,\zeta_s;\theta_n,\nu(t_n)\}\,d\xi\,d\eta \qquad -(18)$$

and the integral extends over the entire area A of the area-source distribution. Similarly for a point-source of strength, say, $Q_P(\xi_r, \eta_r, \zeta_r; t_n)$ at (ξ_r, η_r, ζ_r)

$$Q_V(\xi, \eta, \zeta; t_n) = Q_P(\xi_r, \eta_r, \zeta_r; t_n)\,\delta(\xi - \xi_r)\,\delta(\eta - \eta_r)\,\delta(\zeta - \zeta_r) \quad -(19)$$

and equation (16) then reduces to the definition of the dispersion function $R\{\ \}$, namely

$$C(x, y, z; t_n) = Q_P(r; t_n)\,R\{x - \xi_r, y - \eta_r; z, \zeta_r; \theta_n, \nu(t_n)\} \quad -(20)$$

where we use the abbreviated notation $Q_p(r;t_n)$ to denote the strength of the r-th point source (at ξ_r, η_r, ζ_r) for the time interval t_n.

In current urban air quality models it is customary to consider the pollutant emissions in terms of a limited number, say J, of elevated <u>point-sources</u>, together with horizontal <u>area-sources</u>, the latter being possibly located at a few distinct heights ζ_s(say, for example, s = 1,2,3, as in Hrenko and Turner (1975)). In this case equation (16) reduces to

$$C(x, y, z; t_n) = \sum_{s=1}^{3} \iint_A Q_A(\xi, \eta, \zeta_s; t_n)\,R\{x - \xi, y - \eta; z, \zeta_s; \theta_n, \nu(t_n)\}\,d\xi\,d\eta$$

$$+ \sum_{r=1}^{J} Q_P(r, t_n)\,R\{x - \xi_r, y - \eta_r; z, \zeta_r; \theta_n, \nu(t_n)\} \quad -(21)$$

Introducing (as in (3)) new position variables by

$$X = x - \xi \quad , \quad dX = -d\xi \quad , \quad X_r = x - \xi_r$$
$$Y = y - \eta \quad , \quad dY = -d\eta \quad , \quad Y_r = y - \eta_r \qquad (22)$$

equation (22) may be rewritten

$$C(x,y,z;t_n) = \sum_{s=1}^{3} \iint_A Q_A(x-X, y-Y; \xi_s, t_n) R\{X, Y; z, \xi_s; \theta_n, \nu(t_n)\} dX dY$$
$$+ \sum_{r=1}^{J} Q_P(r;t_n) R\{X_r, Y_r; z, \xi_r; \theta_n, \nu(t_n)\} \qquad (23)$$

In this equation the spatial variables all refer to the fixed coordinate system and we use equation (6) to express the function R{ } in terms of a function K{ } that does not explicitly involve the wind direction θ_n. In the great majority of urban air quality considerations attention is also restricted to ground level concentrations, i.e., values of $C(x,y,0;t_n)$.

V. Gaussian Plume Models and Influence of Finite Mixing Depth

The preceding analysis of multiple-plume models has been in terms of a general plume-dispersion function R{ }, and a few simple assumptions such as the additivity of concentrations, the quasi-steady state concept, horizontal homogeneity of the basic source-receptor relationship, and the

independence of plume dispersion with regard to the actual direction of the wind flow over the urban area. We now consider the special form of the plume dispersion function K of equation (6), for the so-called Gaussian-plume formulation and, as is normally the case, restrict attention to concentrations at ground level (z = 0). Thus we need to consider the form of $K\left\{\underline{X},\underline{Y};0,\zeta;\nu(t_n)\right\}$. The meteorological dispersion index $\nu(t_n)$ actually refers to some specific combination of mean wind speed $U(t_n)$, atmospheric stability category, say $P(t_n)$, and mixing depth $H(t_n)$. For example, if we use a discrete notation this means that each value of $\nu(t_n)$ actually refers to a specific combination, say $U_{\ell(t_n)}$ (ℓ = 1,2,...), $P_{m(t_n)}$ (m = 1,2,...) and $H_{q(t_n)}$ (q = 1,2,...). We will recognize this explicitly in the notation that follows. Thus, for the Gaussian-plume formulation

$$K\left\{\underline{X},\underline{Y};\,0,\xi;\,\nu(t_n)\right\} = 0 \quad \text{if } \underline{X} \leq 0 \tag{24}$$

so that there is no "upwind" transport of material from a source, and

$$K\left\{\underline{X},\underline{Y};0,\xi;\nu(t_n)\right\} = \frac{\exp\left\{-\dfrac{\underline{Y}^2}{2\sigma_y^2\left\{P_m;\underline{X}\right\}}\right\}\exp\left\{-\dfrac{\xi^2}{2\sigma_z^2\left\{P_m,H_q;\underline{X}\right\}}\right\}}{\pi\, U_\ell\, \sigma_y\left\{P_m;\underline{X}\right\}\sigma_z\left\{P_m,H_q;\underline{X}\right\}} \tag{25}$$

where the indices ℓ,m,q are all (random) functions of the time interval t_n. Note in (25) that the "crosswind" standard deviation function σ_y is a function only of the stability category P_m and "downwind" distance $\underline{X}$, although the vertical standard deviation function σ_z is a function also of the mixing depth H_q. This is to reflect the fact that unless the mixing depth is "infinite," the diffusion is limited in the vertical direction, although we assume that the crosswind spread is unaffected. When the vertical diffusion is limited, such as when the pollutant is trapped between the ground surface and a stable air layer aloft, a uniform vertical distribution of concentration would be expected throughout the depth of the mixing layer for sufficiently large values of $\underline{X}$.

Several methods have been proposed to handle this situation (including the use of the classical "method of images" which leads to an infinite series expansion for the function $K\{\ \}$). Here we will consider only one simple method that has been suggested by Pasquill (1974, pp 369-72). This involves consideration of ground level concentrations only. For relatively small values of $\underline{X}$ (or in the case of $H_q = \infty$), it is assumed that $\sigma_z\left\{P_m, H_q; \underline{X}\right\}$ is independent of H_q and given by some simple relationship, such as a power law

$$\sigma_z\left\{P_m, \infty; \underline{X}\right\} = a_z \underline{X}^{b_z} \tag{26}$$

where a and b are constants that are functions of the stability category P_m. If the mixing depth is not infinite, but finite with value H_q, then (26) is used to downwind distances $\underline{X}$ such that*

$$\sigma_z\{P_m, \infty; \underline{X}\} \leq \tfrac{1}{2} H_q \qquad (27)$$

say, for $\underline{X} \leq \underline{X_o}$. Thus from (26), $\underline{X_o} = (H_q/2a_z)^{1/b_z}$. As a rough working rule it is then assumed that the development of a uniform vertical concentration distribution "which <u>per se</u> introduces a roughly two-fold reduction in the ground concentration, is accomplished in a further distance $\underline{X_o}$." For intermediate distances a linear increase of σ_z with distance is assumed. Thus we have for use in (25)

$$\left.\begin{aligned} \sigma_z\{P_m, H_q; \underline{X}\} &= a_z \underline{X}^{b_z} && \text{for } \underline{X} \leq \underline{X_o} \\ &= \frac{H_q \underline{X}}{2\,\underline{X_o}} && \text{for } \underline{X_o} \leq \underline{X} \leq 2\underline{X_o} \\ &= \text{const.} = H_q && \text{for } \underline{X} \geq 2X_o \end{aligned}\right\} \qquad (28)$$

A slightly different scheme has been proposed by Koch and Thayer (1971). With equations (28) the dispersion function K of equation (25) can be evaluated for all values of $\underline{X}$, once the functions $\sigma_y\{P_m; \underline{X}\}$ and $\sigma_z\{P_m, H_q; \underline{X}\}$ have been specified.

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* Actually, Pasquill takes $\sigma_z \leq H_q \Big/ \sqrt{2 \log_e 10}$, i.e., $\sigma_z \leq H_q \Big/ 2.15$

Finally, we may note that although we have spoken in this section of a single mean wind speed value $U(t_n)$ or $U_{\ell(t_n)}$ ($\ell = 1,2...$), it is clear from equation (23) that we could if desired for each t_n associate a different wind speed with each of the J dispersion functions for the elevated point-sources and likewise with each of the dispersion functions for the three levels of the area-sources. This might be done in such a way as to more realistically reflect the known increase of wind speed with height above the ground, say, by using a simple power law function of height z (Calder (1971)). When we come later to consider time-averages in terms of a joint frequency function of the meteorological conditions $f(\theta,v) = f(\theta,U_\ell,P_m H_q)$ we may also use different wind speeds as above, since the permissible discrete values U_ℓ for each level will obviously have the same frequency distribution as those for some standard level set of U_ℓ values.

VI. Area-Source Contribution Using Narrow Plume Hypothesis

Considerable simplification in the calculation of the area-source contributions in equation (23) can be made using the "narrow plume hypothesis" (unpublished note by K. L. Calder to F. Gifford "A Narrow Plume Simplification for Multiple Source Urban Pollution Models," dated 31 Dec 1969). This simplification* was specifically implemented by Koch and Thayer (1971, 1974) under a contract with the U.S. Environmental Protection Agency. We first rewrite equation (23) for just one of the

* The simplification has also been proposed and utilized independently by Gifford and Hanna (1970).

area integrals, using equation (6) and the wind-oriented coordinate system of (5), i.e., we change the (dummy) integration variables from (X,Y) in (23) to ($\underline{X}$,$\underline{Y}$) and note that $dXdY = d\underline{X}d\underline{Y}$. Then

$$C(x,y,z;t_n) = \iint_A Q_A\left(x-\left[\underline{X}\cos\theta_n - \underline{Y}\sin\theta_n\right], y-\left[\underline{Y}\cos\theta_n + \underline{X}\sin\theta_n\right], \xi_s; t_n\right) K\{\underline{X},\underline{Y}; z, \xi_s; \nu(t_n)\}\, d\underline{X}\, d\underline{Y} \qquad -(29)$$

Now it is clear that if the concentration in a point-source plume decreases rapidly with crosswind distance from the plume centerline, then in the integration with respect to $\underline{Y}$ in equation (29) the function $K\{\ \}$ will be small except for small values of $|\underline{Y}|$. We assume that in practice (and certainly when large grid areas are used to specify the area-source intensities) that this distance is sufficiently small so that $\underline{Y}$ variations of the area-source strength function Q_A can be disregarded. This situation can be thought of in a formal manner, by using the Dirac δ-function and writing

$$K\{\underline{X},\underline{Y}; z, \xi_s; \nu(t_n)\} = G\{\underline{X}; z, \xi_s; \nu(t_n)\}\,\delta(\underline{Y}) \qquad -(30)$$

Then since

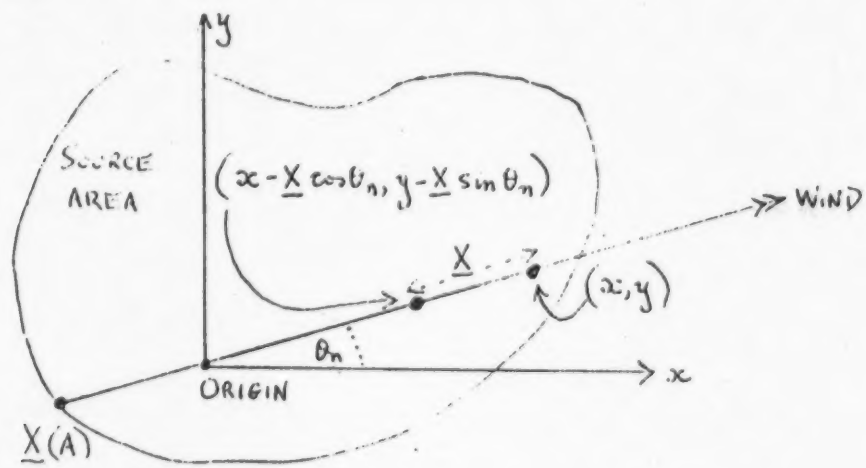
$$\int_{-\infty}^{0} K'\{\underline{X}, \underline{Y}; z, \xi_s; \nu(t_n)\}\, d\underline{Y} = G\{\underline{X}; z, \xi_s, \nu(t_n)\} \int_{-\infty}^{\infty} \delta(\underline{Y})\, d\underline{Y}$$

$$= G\{\underline{X}; z, \xi_s; \nu(t_n)\} \qquad -(31)$$

the function G represents the crosswind integrated concentration from a unit point source. With (31), equation (29) reduces to the form

$$C(x, y, z; t_n) = \int_{0}^{\underline{X}(A)} Q_A(x - \underline{X}\cos\theta_n, y - \underline{X}\sin\theta_n, \xi_s; t_n)\, G\{\underline{X}; z, \xi_s; \nu(t_n)\}\, d\underline{X} \qquad -(32)$$

[The δ-function selects just the value of the integrand corresponding to $\underline{Y} = 0$]. We note that the source function Q_A refers to the original fixed coordinate system.



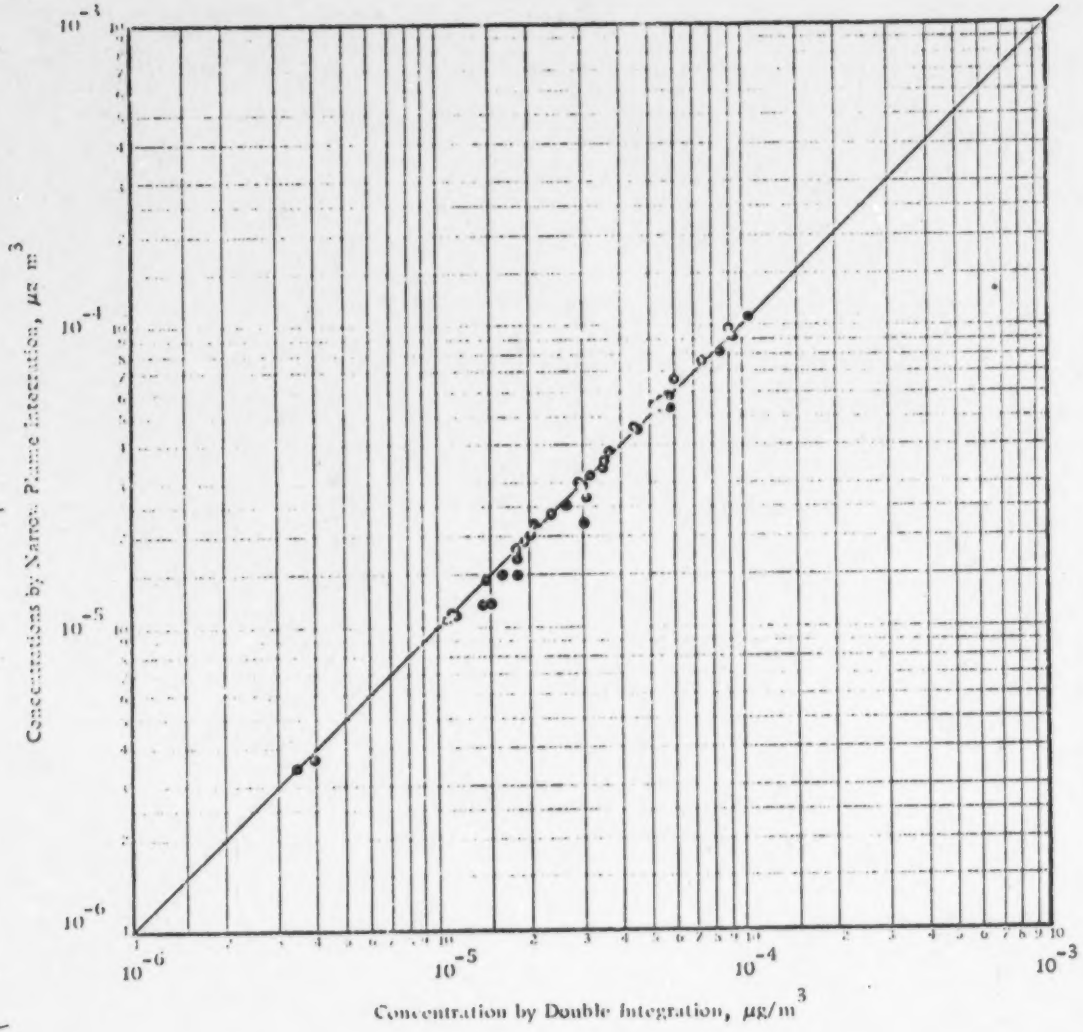


Figure 8. Comparison of Model Calculations Using Narrow Plume and Double Integration Approaches Using Portion of St. Louis Data (See Text)

Equation (32) only involves values of Q_A along a line directly upwind from the receptor location (x,y), and extending to the upwind edge of the source area, say $\underline{X}(A)$. The lower limit of integration is zero since G (like the dispersion function K) is zero for negative values of $\underline{X}$, i.e. locations upwind of the receptor location.

The above simplification leads to a major saving of computer time, since it is only necessary to evaluate numerically a one-dimensional integral rather than the original two-dimensional one. Implementation of this concept was one of the major objectives of the short-term model described by Koch and Thayer (1971). A comparison of concentration predictions using the narrow plume approximation and those by the double integration of equation (29) are shown in Figure 8 of the Koch-Thayer report, which is reproduced here. The calculations were made for some 40 receptor locations and for a realistic area-source distribution at St. Louis, Missouri, covering an area of 30 Km x 40 Km. It is seen that the two sets of concentration values are highly clustered about the equality line, which justifies the use of the narrow plume approximation. This approximation is also utilized in the more recent RAM algorithm (Hrenko-Turner (1975)). The use of the double integration procedure has been described by Fortak (1969, 1974).

It may be noted that with the Gaussian-plume approximation it follows from (25) and (31), that for ground level concentrations

$$G\{\underline{X}\,;\,0,\xi_s\,;\,\nu(t_n)\} = \sqrt{\frac{2}{\pi}}\;\frac{\exp\left\{-\dfrac{\xi_s^2}{2\,\sigma_z^2\{P_m, H_q\,;\,\underline{X}\}}\right\}}{U_\ell\,\sigma_z\{P_m, H_q\,;\,\underline{X}\}} \qquad (33)$$

Since in practice the source function Q_A appearing in equation (32) is piece-wise constant, the integral is actually the sum of integrals of the form

$$I = Q_A \int_{\underline{X}_1}^{\underline{X}_2} G\{\underline{X}\,;\,0,\xi_s\,;\,\nu(t_n)\}\,d\underline{X} \qquad (34)$$

where Q_A is a constant. With the Gaussian form (33) and a simple power law for the σ_z-function (equation (26)), the integral (34) then reduces to an Incomplete Gamma Function. It may also be expressed in terms of known analytical functions when the extended formulation of equations (28) is used. However, it may still be simpler in practice to evaluate the integral directly by numerical integration techniques.

VII. Long-Term Average Concentration Values

In a previous section we have discussed in general terms the frequency distribution of the short-term concentration values and also the long-term averages. If the emissions and meteorological conditions cannot be regarded as independent in a statistical sense, then the long-term averages must be obtained from equation (15) in terms of the estimated cumulative frequency

function F(c) for the short-term values. The latter must be obtained by an appropriate sampling of concentration values as calculated from equation (23), which gives the total short-term concentration from the point- and area-source emission distributions. A suitable procedure is described by Koch and Thayer (1971; also 1973, 1974, 1975). With the narrow plume hypothesis equation (23) may be rewritten as

$$C(x,y,z;t_n) = \sum_{s=1}^{S} \int_0^{X(A)} Q_A(x-\underline{X}\cos\theta_n, y-\underline{X}\sin\theta_n, \xi_s; t_n)\, G\{\underline{X}; z, \xi_s, \nu(t_n)\}\, d\underline{X}$$

$$+ \sum_{r=1}^{J} Q_P(r;t_n)\, R\{X_r, Y_r; z, \xi_r; \theta_n, \nu(t_n)\} \quad -(35)$$

However, as we have seen previously, if the emissions and the meteorological conditions can be treated as independent, then the long-term average concentration values may be calculated directly and without using the short-term values and their frequency distribution. Such an analysis was the basis for the so-called climatological dispersion model (CDM) described by Calder (1971), and for which a user's guide is now available (Busse and Zimmerman (1973)). We now consider how the long-term average values may be obtained from the basic short-term equation (35) that uses the narrow

plume approximation. Note first that the area-source strength functions Q_A in (35) are functions of the wind direction θ_n, i.e., are meteorologically dependent, in contrast, for example, to the Q_A's appearing in equation (23). To obtain the long-term average concentration value it will be convenient to use a polar coordinate system (ρ,ψ) with origin at the receptor location. Then (with an obvious slight change of notation that will cause no confusion) if $Q_A(\rho,\psi)$ now denotes the area source-strength at (ρ,ψ), so that $Q(\rho,\psi)\rho d\psi d\rho$ is the total emission from the element of area $\rho d\psi d\rho$ surrounding the point (ρ,ψ), we may rewrite any one of the area-source integrals in (35) as, say

$$I = \int_0^{\rho(A)} Q_A(\rho, \theta_n, \xi_s; t_n)\, G\{\rho; z, \xi_s; \nu(t_n)\}\, d\rho \qquad -(36)$$

Now for a fixed value of θ, provided the emissions and dispersion function $G\{\ \}$ are statistically independent, the average value of the integrand (here over all possible values of the dispersion index ν) will be

$$\bar{Q}_A(\rho, \theta, \xi_s) \sum_{\nu} f(\theta, \nu)\, G\{\rho; z, \xi_s; \nu\}$$

where $\bar{Q}_A(\rho,\theta,\xi_s)$ denotes the average source-strength and $f(\theta,\nu)$ is the joint frequency function for wind direction θ and dispersion index ν. Considering now all possible values of θ it follows from (36) that the average value

$\bar{I}$ will be given by

$$\bar{I} = \oint \int_0^{\rho(A)} \bar{Q}_A(\rho,\theta,\xi_s)\left[\sum_\nu f(\theta,\nu)\, G\{\rho; z, \xi_s; \nu\}\right] d\theta\, d\rho \qquad -(37)$$

As a special example (Calder (1971)) consider the case where the frequency function $f(\theta,\nu)$ is assumed to be piece-wise constant in the 22 1/2° wind sectors of a 16-point compass, and let $\phi(k,\nu)$ denote the total joint frequency for the k-th wind sector and dispersion index ν, so that

$$f(\theta,\nu) = \frac{16}{2\pi}\,\phi(k,\nu) \quad ; \quad (k-1)\left(\frac{2\pi}{16}\right) < \theta \leq k\left(\frac{2\pi}{16}\right) \qquad -(38)$$

Then (37) becomes

$$\bar{I} = \frac{16}{2\pi}\sum_{k=1}^{16}\sum_\nu \phi(k,\nu)\int_0^{\rho(A)} G\{\rho; z, \xi_s; \nu\}\left[\int_{k\ \text{sector}} \bar{Q}_A(\rho,\theta,\xi_s)\, d\theta\right] d\rho \qquad -(39)$$

or with

$$\psi_k(\rho) = \int_{k\ \text{sector}} \bar{Q}_A(\rho,\theta,\xi_s)\, d\theta$$

this becomes

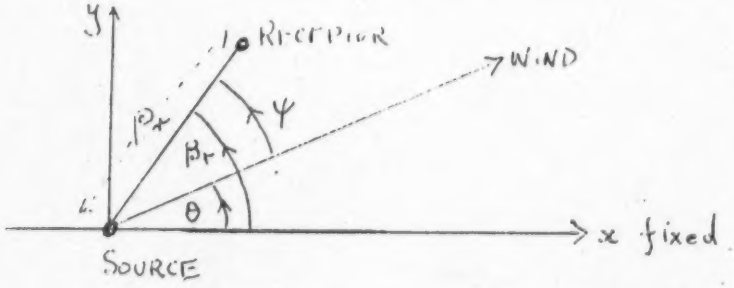
$$\bar{I} = \frac{16}{2\pi}\int_0^{\rho(A)} \sum_{k=1}^{16} \psi_k(\rho)\sum_\nu \phi(k,\nu)\, G\{\rho; z, \xi_s; \nu\}\, d\rho \qquad -(40)$$

This equation is identical with that obtained for the area-source concentration contribution in the climatological model for multiple-source urban air pollution (Calder (1971), equation (17)). The narrow plume hypothesis as used in equation (35) is thus entirely consistent with the long-term average results for the area-sources from the earlier model.

Turning now to the average value of the point-source contribution in equation (35), since the emissions and meteorology are to be considered as statistically independent, the average concentration will be equal to the product of the average source strength value, say $\overline{Q}_p(r)$ and the average value of the dispersion function $\overline{R}\{\ \}$. To evaluate the latter we use a wind-oriented coordinate system (equation (5)) and replace R by the function $K\left\{\underline{X}_r, \underline{Y}_r; z, \zeta_r; \nu\right\}$ through equation (6). Here the underbars denote coordinates relative to the wind-oriented system and $\underline{X}_r, \underline{Y}_r$ are both functions of θ. Then the average value of the dispersion function is

$$\sum_{\nu} \oint K\left\{\underline{X}_r, \underline{Y}_r; z, \zeta_r; \nu\right\} f(\theta, \nu)\, d\theta \qquad -(41)$$

Now use a polar coordinate system with ρ_r = source-receptor distance and β_r = angle of this direction from x-axis



Then considering first the integration with respect to θ in (41) we have, say

$$I_r = \oint K\{\underline{X_r} = \rho_r \cos(\beta_r - \theta), \underline{Y_r} = \rho_r \sin(\beta_r - \theta); z, \xi_r; \nu\} f(\theta, \nu) d\theta$$

$$= \oint K\{\underline{X_r} = \rho_r \cos\psi, \underline{Y_r} = \rho_r \sin\psi; z, \xi_r; \nu\} f(\beta_r - \psi, \nu) d\psi \qquad (42)$$

Now under the narrow plume hypothesis the dispersion function $K\{\ \}$ is strongly peaked with a maximum at $\psi = 0$, i.e. the wind is directly from source to receptor. Also for small ψ, $\cos\psi = 1$, $\sin\psi = \psi$ and $f(\beta_r - \psi) = f(\beta_r)$. Hence I_r above is approximated by

$$I_r \doteq \oint K\{\rho_r, \rho_r\psi; z, \xi_r; \nu\} f(\beta_r, \nu) d\psi$$

$$= f(\beta_r, \nu) \int_{-\infty}^{\infty} K\{\rho_r, y; z, \xi_r; \nu\} \frac{dy}{\rho_r}$$

$$= \frac{f(\beta_r, \nu)}{\rho_r} G\{\rho_r; z, \xi_r; \nu\} \qquad (43)$$

by equation (31). We note that $I_r\overline{Q}_r$ is the average concentration produced by the r-th point source for the dispersion index ν and is the starting point for the climatological dispersion model (Calder (1971), equation (12)). This average value does not involve the crosswind standard deviation function σ_y (when a Gaussian-plume formulation is used), but only the vertical standard

deviation function σ_z. The average value is the product of an "isotropic" dispersion function G/ρ_r that depends only on vertical dispersion and the joint frequency function $f(\beta_r, \nu)$. Although the average value relates to all possible wind directions, the narrow plume approximation makes it possible to relate this average value to the frequency function for a particular wind direction, viz, the source-receptor direction.

To obtain the average concentration for the r-th point source we must still average over the dispersion index ν. Thus finally the average (single) point-source concentration is

$$\bar{C}(x,y,z) = \sum_{\nu} \frac{\bar{Q}(r)\, G\{\rho_r; z, \xi_r; \nu\}}{\rho_r} f(\beta_r, \nu)$$

and using (38)

$$\bar{C}(x,y,z) = \frac{16}{2\pi} \sum_{\nu} \frac{\bar{Q}(r)\, G\{\rho_r; z, \xi_r; \nu\}}{\rho_r} \phi(k_r, \nu) \qquad -(44)$$

if the r-th point-source lies in the k_r-th 22 1/2° wind sector (k_r = 1,2...16). This formula is identical with that given for the long-term climatological model (Calder (1971), equation (14)).

We have thus shown that for both point- and area-sources, under the special circumstance that the emissions and meteorological conditions can be treated as statistically independent, i.e., uncorrelated, the long-term average concentration values based on the use of the short-term prediction equation (35) [and that uses the narrow plume approximation for the area-source contributions] will be identical with those obtained using the "climatological" model and which uses only the average emission values and the joint frequency function $f(\theta,v)$ of meteorological conditions. As indicated, the climatological model stems from the basic formula (43) as a source-receptor relation for a single point source. The results for area-sources are then obtained by an area integration. We have shown, however, that the climatological model results could equally well have been obtained by averaging the short-term equation (35), i.e., when the emissions and meteorology are statistically independent, the short- and long-term model results are entirely consistent.

VIII. Concentration Frequency Distribution

We return to a discussion of the frequency distribution as given by equation (9), for the ensemble of concentration values $C(x,y,z;t_n)$ $[n = 1,2,...]$. To avoid the necessity for the inordinate amount of computation that would be required to determine the total population of C-values, the frequency distribution (or any other statistical property) must be based on the selection of an appropriate sample of C-values. One such sampling procedure, described

as "proportionate stratified sampling" has been described by Koch and Thayer (1971) and is appropriate in the general case where it may not be legitimate to assume that the emissions and meteorological dispersion functions are statistically independent. In this case it would not be possible to estimate the concentration frequency distribution simply in terms of a joint frequency function for meteorological conditions alone, but this would require consideration of a frequency function for emissions and meteorology jointly.

In practice it is very rarely that detailed short-term information is available for both point-source and area-source emissions from an urban area, and concentration estimates must frequently be based on quite crude estimates of the long-term average values. Provided the emissions and the meteorological conditions are uncorrelated, then these average values are those actually required by the theoretical formulation for long-term concentration values, and the average emissions can then be used together with a joint frequency function for the meteorological conditions alone. However, in the absence of more detailed information these average emission values are also frequently used as a basis for calculating the concentration frequency distribution even though this procedure is not strictly valid unless the temporal variation of the emissions can be disregarded.

We now consider this calculation of the concentration frequency function in terms of the average emission rates and the joint frequency function ($f(\theta,v)$ for the meteorological conditions alone. For the simple plume-type models under consideration $f(\theta,v)$ is actually an abbreviated notation,

where each value of the dispersion index ν refers to a specific combination of mean wind speed $U_\ell (\ell = 1,2,...)$, stability category P_m $(m = 1,2,...)$ and mixing depth $H_q (q = 1,2,...)$. Thus $f(\theta,\nu) \equiv f(\theta,U_\ell,P_m,H_q)$ and is really a joint-frequency function for the 4 meteorological variables θ, U_ℓ, P_m and H_q. In the present analysis this function is regarded as of mixed continuous-discrete type, with θ a continuous variable, although U_ℓ, P_m and H_q are assumed to have discrete distributions. The continuous distribution with regard to θ may be contrasted with the formulation of Koch and Thayer (1971) and Fortak (1969), where only discrete values of wind direction are considered at 10° intervals.

Up to the present time little use appears to have been made of the 4-variable frequency function $f(\theta,U_\ell,P_m,H_q)$ and for simplicity it is frequently assumed (e.g., Calder (1971)) that the mixing depth H_q is determined by the stability category, so that in this case we need only consider a 3-variable function $f(\theta,U_\ell,P_m)$ such that

$$\sum_{\theta}\sum_{\ell}\sum_{m} f(\theta, U_\ell, P_m) = 1 \qquad -(45)$$

where the summation over θ is actually an integration and the frequency function f is obtained from the more common wind-sector frequency function using equations similar to (38) [10° wind sectors are now in standard use for the ϕ-function].

To obtain a sampling of the total ensemble of concentration values $C(x,y,z;t_n)$ as given by equation (35) [we use the narrow plume approximation, but also additionally the average emission values $\bar{Q}_A(x-\underline{X}\cos\theta_n, y-\underline{X}\sin\theta_n, \zeta_s)$ and $\bar{Q}_p(r)$ in evaluating (35)] we proceed in three steps*

Step 1

First form the marginal frequency function (continuous) for wind direction defined by [with cumulative frequency function $H(\theta)$].

$$h(\theta) = \sum_{\ell}\sum_{m} f(\theta, U_\ell, P_m) \qquad -(46)$$

The function $h(\theta)$ will be piecewise constant in θ. For example, in the case of wind frequency data derived from a 16-point compass of 22 1/2° wind sectors (see equation (38))

$$h(\theta) = \frac{16}{2\pi}\sum_{\ell}\sum_{m} \phi(k,\ell,m) \quad ; \quad (k-1)\left(\frac{2\pi}{16}\right) < \theta \leq k\left(\frac{2\pi}{16}\right) \qquad -(47)$$

where $\phi(k,l,m)$ is the total joint frequency for the k-th wind sector and wind speed U_ℓ and stability category P_m. The cumulative frequency function, say $T = H(\theta)$, $[0 \leq T \leq 1]$, will be a continuous monotonic-increasing function of θ. Let the T-axis now be subdivided into say N (perhaps 300) equal intervals by points $T_0, T_1, \ldots T_n$ and replace the continuous distribution

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* The author gratefully acknowledges critical discussions on this question with Mr. John Irwin of the Meteorology and Assessment Division, EPA, and through him indirect consultation with Dr. C. H. Proctor of the North Carolina State University

$H(\theta)$ by a discrete distribution of point probabilities $p_s (s = 1,2,\ldots N)$ at $\theta = \psi_s$ where $T_s = H(\psi_s)$ and $p_s = H(\psi_s) - H(\psi_{s-1})$. Then $p_s = T_s - T_{s-1} = \text{const} = 1/N$ [A refinement of this method would start from a random point on the T-axis rather than the origin, and then step out equal intervals, treating T as a closed curve]. The discrete distribution

$$p_1 \text{ at } \psi_1 \,,\; p_2 \text{ at } \psi_2 \,, \cdots\cdots p_N \text{ at } \psi_N$$

is one of equal frequencies

$$p_1 = p_2 = \cdots\cdots = p_N = \frac{1}{N}$$

having the same cumulative frequency function as $H(\theta)$ at the N values of θ.

Step 2

Randomly index each possible combination (U_ℓ, P_m) by an index number, say $\lambda = 1,2,\ldots M$. From the wind-sector frequency function $\phi(k,l,m)$ (assumed to be provided from climatological records form $f(\psi_s, U_\ell, P_m)$ for each $\psi_s (s = 1,2,\ldots N)$ defined in Step 1 and for each (l,m) combination, i.e., value of the index number λ. For this purpose we use equations similar to

$$f(\psi_s, U_\ell, P_m) = \frac{16}{2\pi}\phi(k,l,m) \;;\; (k-1)\left(\frac{2\pi}{16}\right) < \psi_s \leq k\left(\frac{2\pi}{16}\right) \quad -(48)$$

$$k = 1, 2, \ldots 16$$

which is appropriate to a 22 1/2° ($= \frac{2\pi}{16}$ radian) wind-sector. Then construct the discrete joint cumulative frequency function $E(\psi_s, \lambda)$ [$s = 1,2,\ldots N$, $\lambda = 1,2,\ldots M$].

We now make use of the basic fact that for any cumulative frequency function, say $F(y)$, the solutions y of the equations $u = F(y)$ for different values of u form a sequence of independent random numbers with the cumulative frequency function $F(y)$ provided the u-values are a sequence of random numbers from a uniform distribution in the interval (0,1). This method of generating random numbers having a given cumulative distribution function is called the "inverse function since $y = F^{-1}(u)$ [See Handbook of Mathematical Functions, N.B.S. Applied Mathematics Series 55, June 1964]. We now use this inverse-function method to generate random λ-values, say λ_s for each ψ_s from the cumulative functions $E(\psi_s,\lambda)$. Each λ_s value will define a wind speed-stability combination, and we use this random sampling procedure to obtain random wind-speed-stability combinations to associate with each of the values of ψ_s ($s = 1,2,\ldots N$) and each of the N point-probabilities in Step 1.

Step 3

Finally, the cumulative frequency distribution function $F(c)$ for the total concentration C at a receptor location (C is here regarded as a random variable given by equation (35)) is given by

$$F(c) \quad \sum_{\substack{s \\ C(\psi_s,\lambda_s) \leq c}} p_s \quad \left(p_s = \frac{1}{N}\right) \qquad -(48)$$

where the summation over s is to be taken only for those values of s for which the inequality on C is satisfied, where $C(\psi_s,\lambda_s)$ is the concentration

value given by (35) [with ν now replaced by the appropriate λ-value] for the wind direction $\theta = \psi_s$ and with the random wind speed-stability combination λ_s that is associated with it by this sampling procedure.

We note that in the method proposed the wind direction is treated as a continuous variable, i.e., it can assume any value between 0-360°. This is in contrast to some analyses which treat θ as a discrete variable that is capable of assuming only a finite number of values. Since concentration at a receptor depends critically on the wind direction over the urban area it appears desirable to treat it as a continuous variable.

IX. Summary

Multiple-source plume (and particularly Gaussian-plume) models are commonly used for mathematical modeling of concentrations of inert pollutants over urban areas. Although there are many special purpose computational algorithms currently in use, the basic element that is common to most is the simple plume from a single point-source release. The spatial distribution of pollution in such a plume is the underlying model component from a physical-meteorological point of view, and the multiple-source air quality simulation model is then developed by simple superposition of the individual plumes from all the emissions. The latter are then in practice idealized as being either large elevated single point-sources or continuous horizontal area-source distributions of emissions, perhaps at several different heights above ground level.

The starting point for most plume models is the assumption of a quasi-steady state. In spite of the obvious long-term variability of emissions, pollutant concentrations, and the meteorological conditions affecting the transport and dispersion of pollution, it is assumed as a working approximation that this variability can be treated as though it resulted from a time-sequence of different steady states. In urban modeling the time interval is normally relatively short and of the order of 1 hour. The basic plume model is therefore a short-term one and the time-sequence of these is regarded as leading to a random series of (1 hour) concentration values, for which the frequency distribution and long-term average value are of particular interest at different receptor locations. For a pollutant that is chemically inert it is assumed that the concentration contributions at a receptor from individual plumes combine additively, so that the plumes may be simply superimposed to obtain the total effect at the receptor location. Other assumptions normally made are that the dispersion of pollutant is "horizontally homogeneous" and independent of the horizontal location of the source, i.e., the source-receptor relation is invariant under arbitrary horizontal translation of the source-receptor pair. Further, the dispersion in a simple point-source plume is assumed to be "isotropic" as regards direction, and independent of the actual direction of the wind transport over the urban area. In principle the short-term multiple-source plume model then only involves simple summation or integration over all point- and area-sources and for the different meteorological conditions of plume dispersion.

However, since these summations can be made in many different ways and orders, a large number of types of special problems may be analyzed. For example, it is obviously possible, if this is desired, to calculate the concentration contribution at a receptor due to any arbitrary conceptual aggregation of the individual point- and area-sources. This may be important in comparing alternative air pollution control strategies and in cost-benefit type of analysis.

In most short-term plume models in use at the present time, it is assumed that for each time interval of the quasi-steady state sequence the pollutant transport by the wind over the urban area can be characterized in terms of a single "wind-direction." Also for each time interval the other meteorological variables that influence the transport and dispersion of pollution in the individual plume in the urban boundary layer are taken to be the "mean wind speed," the atmospheric "stability category," and the "mixing depth." The latter, when of finite value, will restrict plume dispersion in the vertical direction, and for great enough distances of downwind travel lead to a uniform concentration distribution in the vertical Normally, the crosswind dispersion of the plume is assumed to be unaffected by the value of the mixing depth. Although the wind direction θ is evidently a continuous variable that may assume any value ($0<\theta<360°$), for reasons of practical simplicity the 3-dispersion variables are usually considered as discrete, with a relatively small number of possible values for each. The short-term steady-state 3-dimensional spatial distribution

of concentration for an individual point-source plume must then be capable of expression in terms of these 3 meteorological dispersion parameters for all possible values of the latter. This is done in terms of a plume dispersion function of fixed, i.e., non-stochastic, functional form although the dispersion parameters that form its arguments will, of course, be random variables. Most models assume the well-known simple Gaussian-plume and the horizontal and vertical standard deviation functions σ_y, σ_z that occur in the latter are expressed as functions of the downwind distance in the plume and of the stability category and mixing depth only. The mean wind speed, however, enters separately into the plume concentration formula, and concentrations vary inversely as the wind speed.

Since the typical plume is fairly narrow as compared with the distances that are characteristic of appreciable changes in the area-source emission intensities, it may be shown that the double-integral that must formally be evaluated to obtain horizontal area-source concentration contributions, can be adequately approximated by a single integral that is much easier to evaluate numerically. This can result in a major simplification of the concentration calculations for an urban area, and the "narrow plume approximation" has been incorporated into several operational air quality simulation algorithms.

Computation of the frequency distribution of the concentration at a receptor due to all the point- and area-sources requires consideration of adequate statistical sampling procedures, if an inordinate amount of computation is to be avoided, and adequate techniques have been described

for this purpose. For the short-term model, input information is required on the short-term (hourly) pollutant emissions and short-term meteorological conditions, although information on the short-term emissions is only rarely available. When the emissions and meteorological conditions can be assumed to be statistically independent or uncorrelated, then the short-term multiple-source formulation that is described in the paper leads to long-term average concentration values identical with those given by the so-called "climatological model" for multiple-source urban air pollution that was developed by the EPA. Thus the basic short-term multiple-source model that is formulated has the desirable quality of internal mathematical consistency with the earlier climatological model.

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Practical Demonstration
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Model Description
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NATO/CCMS PANEL ON MODELING

Documentation for Practical Demonstration

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A CLIMATOLOGICAL DISPERSION MODEL FOR 10° WIND SECTORS (CDM 36)

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* This paper is one of a trilogy prepared by the Meteorology and Assessment Division in support of documentation for the demonstration exercise. The other two complementary papers in the set are:

1. A Frequency-Distribution Algorithm for Multiple-Source Short-Term Pollution Concentrations: by John S. Irwin.
2. Multiple-Source Plume Models for Urban Air Pollution - Their General Structure-: by Kenneth L. Calder.

CLIMATOLOGICAL DISPERSION MODEL FOR 10° WIND SECTORS (CDM 36)

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TYPE Multiple Source, Gaussian-Plume, Long-Term

ABSTRACT

The present Climatological Dispersion Model For 10° Wind Sectors (CDM 36) determines long-term (seasonal or annual) quasi-stable pollutant concentrations at any ground-level receptor using average emission rates from point and area sources and a joint frequency distribution of wind direction, wind speed, and stability for the same period. CDM 36 uses wind direction frequency input from 36 directions instead of the original Climatological Dispersion Model (Busse and Zimmerman, 1973) described by Calder (1971) which uses input from 16 directions. Its structure is otherwise almost identical with that of the earlier model.

MODEL VERSIONS

The original version (CDM) used wind direction frequencies for 16 points (22 1/2° sectors) and was specifically developed in response to the modeling requirements of the NATO/CCMS air pollution project. The present version uses wind frequency data for 36 points (10° sectors). This seems more appropriate since wind information has been recorded to 10° on standard meteorological observations since 1964.

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* On assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce

MAJOR DIFFERENCES FROM OTHER MODELS

The CDM is considered as a replacement for the earlier AQDM (Air Quality Display Model, 1969). It differs from the AQDM primarily in the way concentrations are estimated from area sources. The CDM uses a narrow plume simplification as modified for climatological use. This differs from the virtual point source method for area sources used in the AQDM.

The CDM differs from the AQDM in two other ways, namely: 1) Briggs (1971, 1972) plume rise methods are employed rather than the Holland plume rise equation to calculate plume rise from point sources, and 2) a power law increase of wind speed with height that is dependent upon stability is assumed rather than assuming the same wind speed at all heights of pollutant release.

RESULTS - FORM OF OUTPUT

The basic output is in the form of a table giving for each receptor (and actually for up to two different pollutants): 1) the concentration resulting from all area sources, 2) the concentration resulting from all point sources, and 3) the total concentration from both area and point sources.

Optionally, the model will also yield the contribution to concentrations due to point sources and due to area sources from each wind sector. This information is for the preparation of pollution roses.

Another option available is that of punching a card for each receptor giving the concentration due to area sources, the concentration due to point sources, and the total concentration. These cards may be used as input into separate programs to produce isopleth maps. Cards will also be punched for the directional contributions for those receptors if desired. These can also be used with specially devised plotter programs to produce pollution roses.

APPLICATIONS

The 36 point form of the CDM has not yet been applied to any real modeling situation although it would be expected to improve on the performance of the 16 point form of the model. The original CDM using frequency information for 16 points was applied to Ankara, Turkey; St. Louis, and New York. The results for St. Louis are included in: Calder (1971). The results for Ankara are in Zimmerman (1971). The results of the use of the model for New York are in, Turner et al. (1972).

BASIC EQUATIONS

The basic equations are exactly analogous to those for the original climatological model given in Calder (1971) and Busse and Zimmerman (1973).

Area Sources

The average concentration, $\bar{x}_A$, at a particular receptor due to area sources is given by:

$$\overline{\chi_A} = \int_0^\infty \left[\sum_{k=1}^{36} \overline{q_k(\rho)} \sum_{\ell=1}^{6} \sum_{m=1}^{6} \frac{\phi(k,\ell,m)\, S(\rho,H,u_H,P_m)}{\rho} \right] d\rho \qquad (1)$$

where $\overline{q_k(\rho)} = \frac{36}{2\pi} \int Q(\rho,\theta)\, d\theta$ for the k sector

$Q(\rho,\theta)$ = emission rate of the area source per unit area and unit time

ρ,θ = polar coordinates centered on receptor

k = index identifying wind direction sector ($k = 1 \ldots 36$)

ℓ = index identifying the wind speed class ($\ell = 1 \ldots 6$), (See Table 3)

m = index identifying the class of the Pasquill stability category (P_m), where $m = 1, \ldots 6$. (See Table 2)

$\phi(k,\ell,m)$ = joint frequency function for wind direction, wind speed and stability

$S(\rho,H,u_H,P_m)$ = dispersion function defined below in Equations 3 and 4

H = effective height of source above ground level

u_H = representative wind speed for the effective area source height, H

Point Sources

The average concentration, $\bar{x}_p$, at a receptor due to N point sources is given by:

$$\bar{x}_p = \frac{36}{2\pi} \sum_{n=1}^{N} \sum_{\ell=1}^{6} \sum_{m=1}^{6} \frac{\phi(k_n, \ell, m)\, Q_n\, S(\rho_n, H_n, u_h, P_m)}{\rho_n} \qquad (2)$$

where k_n = wind sector appropriate to the nth point source

Q_n = emission rate of the nth point source

ρ_n = distance from the receptor to the nth point source

u_h = wind speed for the physical height, h.

Dispersion Function

For a receptor the basic functional form of $S(\rho, H, u, P_m)$ will be

$$S(\rho,H,u,P_m) = \sqrt{\frac{2}{\pi}}\,\frac{1}{u\,\sigma_z(\rho,P_m)}\,\exp\left(-\frac{1}{2}\left(\frac{H}{\sigma_z(\rho,P_m)}\right)^2\right)\exp\left(\frac{-0.692\,\rho}{u\,T_{\frac{1}{2}}}\right) \qquad (3)$$

if $\sigma_z(\rho,P_m) < 0.8\ L$ and

$$S(\rho,H,u,P_m) = \frac{1}{u\,L}\,\exp\left(\frac{-0.692\,\rho}{u\,T_{\frac{1}{2}}}\right) \qquad (4)$$

if $\sigma_z(\rho,P_m) \geq 0.8L$.

New terms in Equations 3 and 4 are defined as follows:

$\sigma_z(\rho,P_m)$ = vertical dispersion function, i.e., the standard deviation of the pollution concentration in the vertical direction.

H = effective emission height including plume rise

L = the mixing height (See Table 5)

$T_{1/2}$ = assumed half life of pollutant

The possibility of pollutant removal by physical or chemical processes is included in the program by the decay expression exp $(-0.692\rho/u\ T_{1/2})$.

The total concentration for the averaging period is the sum of concentrations of the point and area sources for that averaging period.

Plume Rise

The plume rise for point sources is calculated using the equations of Briggs.

$$\Delta H = 1.6\ F^{1/3}\ u_h^{-1}\ \rho^{2/3} \qquad \text{for } \rho < 3.5x^* \tag{5}$$

and

$$\Delta H = 1.6\ F^{1/3}\ u_h^{-1}\ (3.5x^*)^{2/3} \qquad \text{for } \rho \geq 3.5x^* \tag{6}$$

where

$$x^* = 14\ (m^{-3/2}\ sec^{15/8})\ F^{5/8} \quad \text{if } F \leq 55\ m^4\ sec^{-3}$$

$$x^* = 34\ (m^{-3/5}\ sec^{6/5})\ F^{2/5} \quad \text{if } F > 55\ m^4 sec^{-3}$$

where Δh = plume rise, meters

$F = g\ v_s\ r_s^{\ 2}\ [(T_s - T_a)\ /\ T_s]$, $m^4\ sec^{-3}$

g = acceleration due to gravity, m/sec^2

v_s = average exit velocity of gases of plume, m/sec

r_s = inner radius of stack, meters

T_s = average temperature of gases in plume, °K

T_a = ambient air temperature, °K

u_h = wind speed at stack top, m/sec

ρ = distance from source to receptor, meters

For area sources, the effective height is input to the model.

Dispersion Functions

An analytical approximation to the dispersion curves for the vertical dispersion function $\sigma_z(\rho, P_m)$ is made by using an empirical power law in a piece-wise fashion of the form

$$\sigma_z(\rho, Pm) = a\rho^b \tag{7}$$

The parameters a and b for various stabilities and ranges of distance ρ are given in Table 1. The value of σ_z is limited to an upper value by the mixing height.

Table 1. PARAMETRIC VALUES FOR $\sigma_z(p, P_m)$

Pasquill Stability Class	Distance, meters < 500 a	< 500 b	500 to 5000 a	500 to 5000 b	5000 to 50,000 a	5000 to 50,000 b
1	0.0383	1.2812	0.2539×10^{-3}	2.0886	0.2539×10^{-3}	2.0886
2	0.1393	0.9467	0.4936×10^{-1}	1.1137	0.4936×10^{-1}	1.1137
3	0.1120	0.9100	0.1014	0.9260	0.1154	0.9109
4	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642
5	0.0818	0.8155	0.2527	0.6341	1.2969	0.4421

An initial value of the dispersion function $\sigma_z(o,P_m)$ is used in the program to represent the vertical dispersion created by the roughness of urban topography (buildings). For area sources, it is possible to input a different value of initial σ_z for each stability class, that is, six different values. Normally, however, the same value (30 meters) is used for all stability classes.

The value of initial σ_z for point sources has been made an empirical function of the height of the stack above the ground. For stacks at ground level to 20 meters above the ground level, initial σ_z is assumed to be 30 meters. For stack heights between 20 and 50 meters above the ground level, initial σ_z is decreased linearly according to the equation

$$\sigma_z(0,P_m) = 50 - h \qquad (6)$$

where h is the stack height in meters. For stacks 50 meters above the ground or higher, the value of initial σ_z is zero.

The initial σ_z is included in the model by determining the virtual distance that produces the initial σ_z for the given stability and adding this distance to the physical distance between source and receptor. This total distance is then used in the power law relationship to obtain σ_z.

METEOROLOGICAL PARAMETERS

Stability Classification Technique

The stability classification is based upon Pasquill (1961) for open countryside and presented in an objective form by Turner (1964). Within the urban atmosphere the stability is usually more unstable than in the adjacent rural atmosphere due to increased roughness and release of heat (McElroy and Pooler, 1968). To account for this, modifications were made to the stability classes by decreasing the stability by one class for all but the most unstable category for calculations for area sources. The times of day that the Pasquill type D occurs are considered separately for use with different mixing heights, that is, there is a D day and D night category.

The stability is therefore classified into six classes in the joint frequency distribution according to the open country classification as shown in the following table.

TABLE 2 STABILITY CLASSIFICATION

Stability Index Used in CDM P_m	Open Country Stability	Equivalent Stability for Urban Area	
		Area Sources	Point Sources
1	A	A	A
2	B	A	B
3	C	B	C
4	D (day)	C	D
5	D (night)	D	D
6	E and F	D	D

Specification of Wind Speed for Model

The characteristic wind speed for the various National Weather Service classes (Table 3) is taken as the central wind speed of the class. It should be noted that the characteristic wind speed of the lowest wind speed class was arbitrarily taken as 1.5 meters per second. This means that light winds reported in the first wind speed class were rounded up to this value. Most operational wind instruments do not sense low wind speeds accurately. Operational wind instruments are designed for durability and also to withstand exposure to strong, gusty airflow. For these reasons, most wind sensors have a high starting speed, which can lead to the erroneous reporting of light winds. (Truppi, 1968).

Table 3. CENTRAL WIND SPEEDS

Wind speed class, ℓ	Speed interval, knots	Class wind speed, m/sec
1	0 to 3	1.50
2	4 to 6	2.46
3	7 to 10	4.47
4	11 to 16	6.93
5	17 to 21	9.61
6	>21	12.52

Wind Profile

To account for an increase of wind with height above a height of 10 meters (anemometer height) to the level of emission, a power law of the form

$$u(h) = u_{\ell} \, (h/10)^{p} \tag{9}$$

is used in the computational program. The exponent p, as determined by DeMarrais (1959), depends on the stability class and is given in Table 4.

Table 4. EXPONENTS FOR WIND PROFILE

Stability index used in CDM	Exponent (p)
1	0.1
2	0.15
3	0.20
4	0.27
5	0.27
6	0.45

Mixing Height

The magnitude of the mixing height undergoes considerable diurnal, seasonal, and annual variation. It is impractical to account for all such variations in detail. Nevertheless, some recognition is given to changes in the magnitude of the mixing height by assigning values to different stabilities according to Table 5.

Table 5. MIXING HEIGHT

Stability index used in CDM	Mixing height, meters
1	1.5 L
2	L
3	L
4	L
5	$(L+L_{min})/2$
6	L_{min}

In Table 5, L is the climatological mean value of the mixing height as tabulated by Holzworth (1972) and L_{min} is the nocturnal mixing height for stable conditions.

INPUT DATA

Emissions

The following parameters are required for each point source:

East coordinate of source location, user units

North coordinate of source location, user units

Pollutant emission rate*, g sec^{-1}

Physical stack height (above ground), meters

Stack inside top diameter, meters

Stack gas velocity, m sec^{-1}

Stack gas temperature, °K

The following parameters are required for each area source (Area sources are squares. The side length can be any size determined by the user.):

East coordinate of the southwest corner of the area source, user units

North coordinate of the southwest corner of the area source, user units

Side length of the area source square, user units

Pollutant emission rate from entire area source,* g sec^{-1}

Average effective height of emission for this area source, meters

Meteorology

Values for the joint frequency function ϕ (k, ℓ, m) are needed where k is the index for wind direction sector, ℓ the index for wind speed class, and m is the stability class index. There are 1296 entries in the table for the joint frequency function; many are zero for combinations of

* for up to two pollutants

stability and wind speed that do not occur. The values for the joint frequency function are normally obtained from an execution of the Day-Night (36) version of the STAR program at the National Climatic Center (NCC) using data available at the center. The NCC is located in Asheville, North Carolina.

Two values are needed for mixing height: 1) an annual average afternoon mixing height, and 2) an annual average nocturnal mixing height for stable conditions.

Specialized Additional Input

For each receptor the east and north coordinates are required as well as setting a variable to indicate if data for a pollution rose is desired.

Additional input related to coordinate scales, initial dispersion, and integration intervals over the area source field are required. They are discussed in detail in Busse and Zimmerman (1973).

PROGRAM DESCRIPTION

The program for the CDM and its operation are described in detail in the User's Guide for the Climatological Dispersion Model by Busse and Zimmerman (1973).

APPLICATION OF THIS MODEL

This model is intended for application to multiple sources (both point and area) in urban areas emitting pollutants that can be treated as inert or at most undergoing losses that can be modeled by exponential decay. The averaging time of the model is the same as the period of

record used for the joint frequency distribution and is usually annual or seasonal. Data for less than one month should not be used. The urban area should be in an area of uncomplicated terrain —— flat or gently rolling.

DESCRIPTION OF ANY VALIDATIONS

No actual validations have been accomplished for the 36 point version of the Climatological Dispersion Model, although it would be expected to improve performance over the 16 point version.

The 16 point version, the original Climatological Dispersion Model has been applied to St. Louis, Ankara, and New York. Results of each of these have been published.

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Practical Demonstration
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Model Description
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NATO/CCMS PANEL ON MODELING

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A FREQUENCY-DISTRIBUTION ALGORITHM FOR MULTIPLE-SOURCE SHORT-TERM POLLUTION CONCENTRATIONS*

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* This paper is one of a trilogy prepared by the Meteorology and Assessment Division in support of documentation for the demonstration exercise. The other two complementary papers in the set are:

1. Multiple-Source Plume Models for Urban Air Pollution - Their General Structure -: by Kenneth L. Calder.
2. A Climatological Dispersion Model for 10° Wind Sectors (CDM 36): by D. B. Turner.

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A FREQUENCY-DISTRIBUTION ALGORITHM FOR MULTIPLE-SOURCE SHORT-TERM POLLUTANT CONCENTRATIONS

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ABSTRACT

This paper describes an algorithm for estimating the frequency-distribution of concentration values based on the use of a short-term multiple-source Gaussian plume model of urban air pollution. The algorithm uses the time-averaged emission rates for the spatially distributed point and area sources constituting the urban emissions and a representative sample of the meteorological conditions that affect the transport and dispersion of the pollutant. The latter are specified using Controlled-Selection sampling from the three-dimensional joint-frequency function for wind direction, wind speed, and atmospheric stability.

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A FREQUENCY-DISTRIBUTION ALGORITHM FOR MULTIPLE-SOURCE SHORT-TERM POLLUTANT CONCENTRATIONS

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I. INTRODUCTION

The general structure of the short-term multiple-source Gaussian plume model as currently used for urban air-quality simulations, has recently been discussed by Calder (1976) in a paper prepared for the NATO/CCMS project for the practical demonstration of such models. The prime purpose of the present paper is to provide further discussion of the frequency-distribution of pollutant concentrations of the short-term model. This subject was previously discussed by Koch and Thayer (1971, 1974), in the general context of a time-sequence of short-period (hourly) concentration values resulting from variations, possibly statistically correlated, of both the pollutant emissions and the meteorological conditions of dispersion. To avoid the necessity for an inordinate amount of computation, such as would be necessary for developing frequency-distributions determined from all possible values in the total ensemble, Koch and Thayer (1974) used a statistical procedure, called proportionate stratified sampling, for choosing a relatively small sample of concentration values that were representative. The present paper is primarily related to the question of sampling, although for a less general situation than considered by Koch and Thayer, namely when the emission variations over the time-period corresponding to the ensemble of short-term concentration values can be disregarded and a constant value assumed.

In practice, it is necessary to make this rather crude assumption when detailed information on the temporal fine-structure of the urban emissions is not available. If the emissions can be treated as temporally constant, the concentration frequency-distribution can be calculated for the multiple-source distribution in terms of a joint-frequency function for the meteorological conditions (a joint-frequency function for wind direction, wind speed, and atmospheric stability category). This joint-frequency function is also the meteorological input required in modeling long-term concentration averages such as in the so-called climatological model of urban air-pollution (Calder, 1971). The original climatological model used 22.5° wind sectors for wind direction; whereas, the most recent version uses 10° wind sectors. Specific details of the input parameters required by the most recent version of the climatological model are described in a separate paper by Turner (1976) that has also been prepared for the NATO/CCMS modeling project. It has been shown that the true ensemble-average of the short-term concentration values is identical with the average concentration value provided by the climatological model when there is no correlation between the emissions and the meteorological conditions and average emission values are used for the calculations.

II. BASIC EQUATIONS FOR SHORT-TERM CONCENTRATIONS

For a fuller discussion of the mathematical formulation, reference may be made to the paper by Calder (1976). Although some minor and obvious notational changes are made in the following, this should cause no confusion. We work with a rectangular coordinate system with x-axis along the mean

horizontal wind direction, with y-axis crosswind, and with z-axis vertical. For the multiple-source urban model the pollutant emissions are considered in terms of a limited number (say, N) of elevated point-sources together with an inventory of horizontal area-sources, with the area sources located at a few distinct (effective) heights, H_s (say, for s = 1,2,3). For any time-interval of the short-term model (taken as about 1 hr) the total concentration $\chi(x,y)$ at <u>ground level</u> at the receptor location (x,y,o) will be the sum of the concentration contribution from the distribution of point-sources, say, $\chi_p(x,y)$ and from the area-source distribution, say, $\chi_A(x,y)$, i.e.,

$$\chi(x,y) = \chi_p(x,y) + \chi_A(x,y) \tag{1}$$

where,

$$\chi_p(x,y) = \sum_{r=1}^{N} Q_p(r)\, K(x-\xi_r, y-\eta_r; H_r) \tag{2}$$

$$\chi_A(x,y) = \sum_{s=1}^{3} \iint_A Q_A(\xi,\eta,H_s)\, K(x-\xi, y-\eta; H_s) \tag{3}$$

and $Q_p(r)$ = emission rate of r-th elevated point-source located at position (ξ_r, η_r, H_r), where H_r is the effective height of the emission.

$Q_A(\xi,\eta,H_s)$ = emission rate of horizontal area-source distribution located at effective height H_s, and A denotes the total integration domain of the area-source distributions.

$K(x-\xi, y-\eta; H)$ = source-receptor function that gives the ground level concentration at receptor location (x,y,o) resulting from a point-source of unit strength at (ξ,η,H), where H is the effective height of the emission.

In equations (2) and (3) it is convenient to use new horizontal coordinates

defined by :

$$X = x - \xi \quad , X_r = x - \xi_r$$
$$Y = y - \eta \quad , Y_r = y - \eta_r \qquad (4)$$

and the narrow-plume approximation is used to reduce the two-dimensional integrals of (3) to one-dimensional integrals (Calder, 1976). Then equations (2) and (3) may be replaced by :

$$\chi_p(x,y) = \sum_{r=1}^{N} Q_p(r)\, K(X_r, Y_r; H_r) \qquad (5)$$

$$\chi_A(x,y) = \sum_{s=1}^{3} \int_0^{X(A)} Q_A(x-X, y-\eta, H_s)\, S(X; H_s)\, dX \qquad (6)$$

where

$$S(X; H_s) = \int_{-\infty}^{+\infty} K(X, Y; H_s)\, dY \qquad (7)$$

The function S represents the crosswind integrated ground-level concentration at downwind distance X from a unit point-source at effective height H_s. The integrals in (6) must be evaluated by numerical integration, e.g., the trapezoid rule. They only involve Q_A values for locations that are directly upwind of the receptor location, i.e., on the line y=constant. The lower limit of integration is zero since there is no effect from sources downwind of the receptor; X(A) denotes the x-coordinate of the most upwind point of the area-source distribution as seen looking directly upwind from the receptor. The function here denoted $S(X;H_s)$ also occurs in the formulation of the long-term climatological model (Calder, 1971, 1976) and is the same as the S-function described in the Turner paper (1976). The equations (5) and (6) are the basic equation for a short-term multiple-source plume model and

their use for each time-interval of a sequence generates an ensemble of concentration values. In the present paper time variations of the emissions are disregarded and the long-term average values are used to estimate the concentration values of the ensemble. The concentration values must then be appropriately sampled to provide the concentration frequency-distribution.

For the Gaussian-plume model the dispersion functions K and S above, have the special functional forms :

$$\left.\begin{array}{l} K(X,Y;H) \\ S(X;H) \end{array}\right\} = 0 \quad \text{if} \quad X \leq 0 \tag{8}$$

$$K(X,Y;H) = \frac{\exp\left\{-\dfrac{Y^2}{2\sigma_y^2(P_m,X)}\right\} \exp\left\{-\dfrac{H^2}{2\sigma_z^2(P_m,H)}\right\}}{\pi U_\ell \sigma_y(P_m,X)\,\sigma_z(P_m,H)} \tag{9}$$

$$S(X;H) = \sqrt{\frac{2}{\pi}}\;\frac{\exp\left\{-\dfrac{H^2}{2\sigma_z^2(P_m,H)}\right\}}{U_\ell\,\sigma_z(P_m,H)} \tag{10}$$

where U_ℓ (ℓ= 1,2,..6) is the mean wind speed and P_m (m=1,2...,6) the stability category for the time-interval.

None of the preceeding formulas explicitly involve the wind direction, θ, since it is assumed that the coordinate axes are so oriented that the

wind direction is along the direction of the positive x-axis. The horizontal spatial variables in all the preceding formulas are then related to the corresponding variables for a fixed coordinate system by the standard formulas for a simple rotation of horizontal axes through an angle θ. In the paper of Calder (1976) the wind angle θ is treated as a continuous variable, $0 \leq \theta \leq 360°$, whereas the wind speed and stability category are treated as discrete variables as above. In developing the frequency function algorithm as discussed in the present paper it is convenient for purposes of computation to treat θ as discrete and this has been done in 1° steps i.e., with the wind direction variable $\theta_k (k=1,2,..360)$.

The fourth meteorological variable to enter explicitly into the plume model formulation is the urban mixing depth, say L. If the latter is finite so that dispersion of the pollution is limited in the vertical direction, then for sufficiently large distances of downwind travel in a single plume the pollution becomes uniformly distributed throughout the depth of the layer and the function S of equation (10) above becomes independent of the downwind distance X. This effect is incorporated into the model by making the functional form of S and K depend on the actual value of X (Calder (1976), Turner (1976)) using the formulation described by Turner. Also for the algorithm of the present paper it is assumed that the value of L is determined by the stability category P_m(Turner (1976)). Thus the meteorological joint-frequency function that is needed for consideration of the total ensenble of all meteorological conditions need only be considered in terms of the three variables of wind direction $\theta_k (k=1,2,..360)$, wind speed $U_\ell (\ell=1,2,..6)$ and stability category $P_m (m=1,2,..6)$. We denote this $f(\theta_k, U_\ell, P_m)$.

Since wind directions in climatological records are now normally classified in terms of 10° wind sectors, it is necessary to express (θ_k, U_ℓ, P_m) in terms of say, $\phi(K,\ell,m)$ the total joint frequency for the K-th wind sector (K=1,2,..36). It is assumed that for each K value the total frequency is distributed uniformly between the 10 individual values of k that are contained within it, such that:

$$f(\theta_k, u_\ell, P_m) = \frac{1}{10}\,\phi(K,\ell,m); \quad 10(K-1) < k \leq 10K \qquad (11)$$

K=1,2,..36

k=1,2,..360

with

$$\sum_{k=1}^{360}\sum_{\ell=1}^{6}\sum_{m=1}^{6} f(\theta_k, u_\ell, P_m) = 1 \qquad (12)$$

The total sample space for the meteorological conditions involved in the plume model is thus described by the 360x6x6 categories i.e, 12,960 categories. The frequency function for total pollutant concentration involves the calculation of total concentration from the multiple-source distribution (from equations (5), (6), (9) and (10)) for a representative sample of the meteorological conditions occurring during the period described by the joint-frequency function as given by equation (11). Thus the cumulative-frequency function for concentration F (c) is:

$$F(c) = \text{Prob}\left\{\chi \leq c\right\}$$

which is determined by consideration of the sum:

$$F(c) = \sum_{s} p_s \qquad (13)$$

$$\text{for } \chi(s) \leq c$$

where p_s are the frequencies associated with the individual members of the representative sample of the meteorological conditions, and $\chi(s)$ is used here to denote the corresponding total concentration as calculated from the plume model. All the input used for the calculations are identical with those given by Turner (1976) for a recent version of the climatological dispersion model that uses 10° wind sectors, and are given in the Appendix*.

III. CONTROLLED-SELECTION SAMPLING OF METEOROLOGICAL FREQUENCY FUNCTION

The calculation of a concentration frequency distribution from a short-term multiple-source model has previously been considered by Koch and Thayer (1971, 1974) who have described a procedure of proportionate stratified sampling. This is appropriate in the general case when the meteorological conditions and also the point-and-area- source emissions are assumed to be capable of specification for each time-period of the sequence defining the total ensemble of values. However, we are currently concerned with a frequency algorithm that may be applied when the time-variations of the pollutant emission are disregarded and the meteorological conditions are specified as

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* With the addition of:

$$\sigma_y(P_m, x) = a_y x^{b_y}$$

where a_y and b_y are defined for each stability category, P_m.

an input to a multiple-source model in terms of the joint-frequency function $f(\theta_k, U_\ell, P_m)$. Thus, we consider the selection of a representative sample of "hours" whose distribution is described by the given frequency distribution. The selection process uses systematic sampling of the frequencies in such a way that the probabilities of selection for preferred combinations of wind-direction, wind speed and stability category are increased, while the prababilities of selection for non-preferred combinations are decreased. The design is based heavily on discussions by Raj (1968), Cochran (1963) and Goodman and Kish (1950).

SAMPLING PROCEDURE

Step 1

Let $h(\theta_k) = \sum_{\ell=1}^{6} \sum_{m=1}^{6} f(\theta_k, U_\ell P_m)$; $k=1,2,..360$ (14)

and $\alpha = H(\theta_k)$ be the cumulative frequency function $(0<\alpha\leq 1)$. This is a step function that is constant over every interval not containing any point of the set θ_k, but has steps of height $h(\theta_k)$ at the points θ_k $(k=1,2,..360)$. In order to utilize the procedure of "systematic sampling" to select a sample of size, say n, from the total ensemble of possible combinations of meteorological conditions (n may be as large as 300, and is open to choice) we take n-points at uniform spacing a=1/n along the α-axis. The starting point α_0 is arbitrary and is chosen at random. The successive samples are taken at α_i, where

$$\alpha_1 = \alpha_0 + a, \alpha_2 = \alpha_0 + 2a \cdots \alpha_i = \alpha_0 + ia$$

The range of α_i is considered as a circular list, such that if $\alpha_i > 1.0$, then α_i is redefined as $\alpha_i - 1.00$. With each value of i is associated a value of θ_k, say $\theta_{k(i)}$, defined through the inequalities:

$$H(\theta_{k(i)}) \leq \alpha_i < H(\theta_{k(i)+1})$$

although the <u>same values</u> of k(=1,2,..360) may correspond to <u>several different consecutive values</u> of i if the total number n is sufficiently large. The frequencies of occurrence for different i-values, say p_i, are evidently equal, since $p_i = \alpha_i - \alpha_{i-1} = 1/n$. This procedure replaces the discrete distribution $h(\theta_k)$, (k=1,2..360), by a discrete set of values $\theta_{k(i)}$, each having a frequency of occurrence, p_i, equal to 1/n.

<u>Step 2</u>

Since the same values of k may correspond to several values of i, let θ_{k_μ} (μ=1,2.M) denote the sub-set of <u>distinct</u> k-values (from k=1,2,..360) resulting from the sampling i=1,2..n as provided by Step 1. The value k_μ corresponds to n_μ (μ=1,2..M) such that:

$$\sum_\mu n_\mu = n$$

Then with each wind direction θ_{k_μ} we may associate n_μ combinations of wind speed category and stability category through the joint-frequency function $f(\theta_{k_\mu} U_\ell P_m)$ of equation (11). Now randomly index each possible combination (U_ℓ, P_m), by an index number λ=1,2,..36, and let $\beta_\mu = E(\theta_{k_\mu}, \lambda)$ denote the cumulative frequency function for the index λ, such that:

$$\beta_\mu = E(\theta_{k_\mu}, \lambda) = \sum_{\ell=1}^{6} \sum_{m=1}^{6} f(\theta_{k_\mu}, U_\ell P_m) \qquad (15)$$

Then as before, the range of β_μ is considered as a circular list and an arbitrary starting point is selected at random within the range of β_μ ($0<\beta_\mu \leq 1$. Successive samples are then selected at intervals $b=1/n_\mu$ for each value of μ, using the same procedures used as in Step 1. We thus select n_μ values of λ, say λ_q, (q=1,2,...μ), each corresponding to a specified wind speed and stability category combination. This random sampling procedure associates a random wind speed and stability combination with each of the M distinct values of wind direction θ_{k_μ} (μ=1,2..M) provided by Step 1. Note, for many frequency-distributions M

will be 1 for most θ_{k_μ} when n is less than 360.

Step 3

Finally, the cumulative frequency distribution function $F(\chi)$ for the total concentration, χ, at a receptor location (χ is here regarded as a random variable given by equation (13)) is given by:

$$F(c) = \sum_{\mu} \sum_{q} p \qquad (16)$$

$$\text{for } \chi(\theta_{k_\mu}, \lambda_q) \leq c$$

$$\mu = 1, 2 \ldots M$$

$$q = 1, 2 \ldots n_\mu$$

$$p = p_i = \frac{1}{n}$$

where the summation over μ is to be taken only for those values of μ for which the inequality on χ is satisfied, where $\chi(\theta_{k_\mu}, \lambda_q)$ is the total concentration value calculated from equations (5) and (6) for the wind direction, $\theta = \theta_{k_\mu}$, and with the random wind speed and stability combination defined by λ_q.

REPLICATION

Each sample of n not only provides the information necessary to estimate the cumulative-frequency function of concentration, F(c), but also provides the information necessary to estimate:

$\bar{x}_i$ = mean total concentration for sample i of size n

$$= \frac{1}{n} \sum_{\mu=1}^{M} \sum_{q=1}^{n_\mu} \chi(\theta_{k_\mu}, \lambda_q)$$

Replication, a procedure of comparing results from independent samples gen-

erated using the same technique, is a standard statistical procedure for objectively evaluating the effectiveness of a sampling technique. It was noted earlier in the discussion that n was open to choice. From the results of the replicate samples, an analysis of variance for a "one-way classification" (refer to Miller and Freund (1965)) can be made which will provide a measure of the precision of $\overline{x}_i$ versus sample size n. Without replication the precision of $\overline{x}_i$ versus sample size is not directly available since controlled selection sampling has the tendancy of biasing the within sample variations Raj (1968).

IV. SUMMARY

The short-term multiple-source Gaussian plume algorithm described in this paper was specifically designed for estimating the frequency-distribution of concentration values at ground-level receptors in an urban environment. The narrow plume hypothesis was used to simplify the calculations for area sources. The algorithm is based on average emission rates from point sources and area sources and uses controlled-selection sampling of the joint-frequency distribution of meteorological conditions to describe the meteorology.

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APPENDIX. EQUATIONS AND INPUT FOR ALGORITHM

I. DIFFUSION EQUATIONS

Area Sources

The concentration, χ_A, at a particular receptor due to area sources for a given wind-direction category, wind-speed category, and stability class is given in general form by equations (6), (7) and (9). When a restriction in vertical dispersion exists, the form of $S(X,H_s)$ will vary with distance from the receptor, X, (Turner, 1976) such that:

$$\chi_A(x,y) = \int_0^{X(A)} Q_A(x-X, y, H_s)\, S(X; H_s)\, dX$$

where: for X such that $\sigma_z(P_m, X) \leq 0.8L$

$$S(X; H_s) = \frac{\sqrt{\frac{2}{\pi}}\, \exp\left\{\frac{-H_s^2}{2\sigma_z^2(P_m, X)}\right\} \exp\left\{\frac{-0.692X}{u_\ell T_{1/2}}\right\}}{u_\ell\, \sigma_z(P_m, X)}$$

for X such that $\sigma_z(P_m, X) > 0.8L$

$$S(X; H_s) = \frac{\exp\left\{\frac{-0.692X}{u_\ell T_{1/2}}\right\}}{L\, u_\ell}$$

for X such that $X \leq 0$

$$S(X; H_s) = 0$$

The possibility of pollutant removal by physical or chemical processes is included in the program by the decay expression $\exp(-0.692\, X/u_\ell T_{1/2})$ and $T_{1/2}$ is the assumed half-life of the pollutant.

Point Sources

The concentration, x_p, at a particular receptor due to point sources for a given wind-direction category, wind-speed category, and stability class is given by equations (5) and (9). When a restriction in the vertical dispersion exists, the form of $K(X_r, Y_r, H_r)$ will vary with distance from the receptor, X, (Turner, 1976) such that:

$$x_p(x,y) = \sum_{r=1}^{N} Q_p(r)\, K(X_r, Y_r; H_r)$$

where: for X_r such that $\sigma_z(P_m, X_r) \leq 0.8L$

$$K(X_r, Y_r; H_r) = \frac{\exp\left\{\frac{-Y_r^2}{2\sigma_y^2(P_m, X_r)}\right\} \exp\left\{\frac{-H_r^2}{2\sigma_z^2(P_m, X_r)}\right\} \exp\left\{\frac{-0.692\, X_r}{U_\ell T_{1/2}}\right\}}{\pi\, U_\ell\, \sigma_y(P_m, X_r)\, \sigma_z(P_m, X_r)}$$

for X_r such that $\sigma_z(P_m, X_r) > 0.8L$

$$K(X_r, Y_r; H_r) = \frac{\exp\left\{\frac{-Y_r^2}{2\sigma_y^2(P_m, X_r)}\right\} \exp\left\{\frac{-0.692\, X_r}{U_\ell T_{1/2}}\right\}}{\sqrt{2\pi}\, \sigma_y(P_m, X_r)\, L\, U_\ell}$$

for $X_r \leq 0$

$$K(X_r, Y_r; H_r) = 0$$

The possibility of pollutant removal by physical or chemical processes is included in the program by the decay expression $\exp(-0.692\, X/U_\ell T_{1/2})$ and $T_{1/2}$ is the assumed half-life of the pollutant.

II. PLUME RISE

Point Source

$H_r = H_p(r) + \Delta H(r)$

where H_p = physical stack height of point source r

$\Delta H(r)$ = plume rise in meters above the physical stack height for the specified meteorological conditions.

[Briggs (1971)]

$$\Delta H(r) = 1.6\, F^{1/3}\, u_h^{-1}\, X_r^{2/3} \qquad \text{for } X_r < 3.5\, X^*$$

$$\Delta H(r) = 1.6\, F^{1/3}\, u_h^{-1}\, (3.5 X^*)^{2/3} \qquad \text{for } X_r \geq 3.5\, X^*$$

$$\text{where } X^* = 14\, F^{5/8} \qquad \text{if } F \leq 55\, m^4 sec^{-3}$$

$$X^* = 34\, F^{2/5} \qquad \text{if } F > 55\, m^4 sec^{-3}$$

$$F = g V_s r_s^2 \left[(T_s - T_a) / T_s \right], \; m^4 sec^{-3}$$

g= acceleration of gravity, m/sec^2

v_s= average exit velocity of gases of plume, m/sec

r_s= inner radius of stack, m

T_s= average temperature of gas in plume, °K

T_a= average annual air temperature, °K

U_h= wind speed at stack top, m/sec

X_r= distance from source to receptor, m.

Area Sources

H_s= the effective height of the pollutant emissions is an input to the algorithm.

III. DISPERSION FUNCTIONS

An analytical approximation to the curves of Pasquill (1961) and Gifford (1961) for the vertical dispersions function, σ_z (Pm,X), and the horizontal dispersions function, σ_y (Pm,S), is made by using an empirical power law in the form :

$$\sigma_z(P_m, X) = a_z X^{b_z}$$

$$\sigma_y(P_m, X) = a_y X^{b_y}$$

The parameters a_z,b_z,a_y and b_y for various stabilities and ranges of distance, X, are given in Table 1.

Table 1. Table of parametric values a_z, b_z, a_y and b_y versus Pasquill stability class and distance from source to receptor.

Pasquill Stability class	PARAMETRIC VALUES FOR $\sigma_z(P_m, x)$						PARAMETRIC VALUES FOR $\sigma_y(P_m, x)$	
	Distance, meters						Distance, meters	
	< 500		500 to 5000		5000 to 50,000		< 50,000	
	a_z	b_z	a_z	b_z	a_z	b_z	a_y	b_y
A	0.0383	1.2812	0.0002539	2.0886	0.002239	2.0886	0.57357	0.85794
B	0.1393	0.9467	0.04936	1.1137	0.04936	1.1137	0.33389	0.88890
C	0.1120	0.9100	0.1014	0.9260	0.1154	0.9109	0.22043	0.89264
D	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642	0.14357	0.89181
E	0.0818	0.8155	0.2527	0.6341	1.2969	0.4421	0.09064	0.91388

IV. METEOROLOGICAL PARAMETERS

Stability Classification Techniques

The stability classification is based upon Pasquill (1961) for open countryside and presented in an objective form by Turner (1964). Within the urban atmosphere the stability is usually more unstable than in the adjacent rural atmosphere due to increased roughness and release of heat (McElroy and Pooler, 1968). To account for this, modifications were made to the stability classes by decreasing the stability by one class for all but the most unstable category for calculations for area sources. The times of day that the Pasquill type D occurs are considered separately for use with different mixing heights, that is, there is a D day and D night category.

The stability is therefore classified into six classes in the joint frequency distribution according to the open country classification as shown in the following table.

TABLE 2 STABILITY CLASSIFICATION

Stability Index Used in CDM P_m	Open Country Stability	Equivalent Stability for Urban Area	
		Area Sources	Point Sources
1	A	A	A
2	B	A	B
3	C	B	C
4	D (day)	C	D
5	D (night)	D	D
6	E and F	D	D

Specification of Wind Speed for Model

The characteristic wind speed for the various National Weather Service classes (Table 3) is taken as the central wind speed of the class. It should be noted that the characteristic wind speed of the lowest wind speed class was arbitrarily taken as 1.5 meters per second. This means that light winds reported in the first wind speed class were rounded up to this value. Most operational wind instruments do not sense low wind speeds accurately. Operational wind instruments are designed for durability and also to withstand exposure to strong, gusty airflow. For these reasons, most wind sensors have a high starting speed, which can lead to the erroneous reporting of light winds. (Truppi, 1968).

Table 3. CENTRAL WIND SPEEDS

Wind speed class, ℓ	Speed interval, knots	Class wind speed, m/sec
1	0 to 3	1.50
2	4 to 6	2.46
3	7 to 10	4.47
4	11 to 16	6.93
5	17 to 21	9.61
6	>21	12.52

Wind Profile

To account for an increase of wind with height above a height of 10 meters (anemometer height) to the level of emission, a power law of the form :

$$u_h = u_a \left(\frac{H_p(r)}{10} \right)^p$$

is used in the computational program. The exponent p, as determined by DeMarrais (1959), depends on the stability class and is given in Table 4.

Table 4. EXPONENTS FOR WIND PROFILE

Stability index used in CDM	Exponent (p)
1	0.1
2	0.15
3	0.20
4	0.27
5	0.27
6	0.45

Table 5. MIXING HEIGHT

Stability index used in CDM	Mixing height, meters
1	1.5 L
2	L
3	L
4	L
5	$(L+L_{min})/2$
6	L_{min}

Mixing Height

The magnitude of the mixing height undergoes considerable diurnal, seasonal, and annual variation. It is impractical to account for all such variations in detail. Nevertheless, some recognition is given to changes in the magnitude of the mixing height by assigning values to different stabilities according to Table 5.

In Table 5, L is the climatological mean value of the mixing height as tabulated by Holzworth (1972) and L_{min} is the nocturnal mixing height

for stable conditions.

V. INPUT DATA

Emissions

The following parameters are required for each point source:

East coordinate of source location, user units

North coordinate of source location, user units

Pollutant emission rate*, g sec^{-1}

Physical stack height (above ground), meters

Stack inside top diameter, meters

Stack gas velocity, m sec^{-1}

Stack gas temperature, °K

The following parameters are required for each area source (Area sources are squares):

East coordinate of the southwest corner of the area source, user units

North Coordinate of the southwest corner of the area source, user units

Side length of the area source square, user units

Pollutant emission rate from entire area source,* g sec^{-1}

Average effective height of emission for this area source, meters

Meteorology

Values for the joint frequency function $\psi(K,U_\ell P_m)$ are needed where K is the index for wind direction sector, ℓ the index for wind speed class, and m is the stability class index. There are 1296 entries in

* for up to two pollutants

the table for the joint frequency function; many are zero for combinations of stability and wind speed that do not occur. The values for the joint frequency function are normally obtained from an execution of the Day-Night (36) version of the STAR program at the National Climatic Center (NCC) using data available at the center. The NCC is located in Asheville, North Carolina.

Two values are needed for mixing height: 1) an annual average afternoon mixing height, and 2) an annual average nocturnal mixing height for stable conditions.

Specialized Additional Input

For each receptor the east and north coordinates are required. Additional input related to coordinate scales and number of samples to be generated using the input joint-frequency distribution of meteorology.

3.4 Model results

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Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Nieuwstadt, Engeldal;
The Netherlands (KNMI)

K O N I N K L I J K N E D E R L A N D S
M E T E O R O L O G I S C H I N S T I T U U T

D e B i l t

WETENSCHAPPELIJK RAPPORT

W.R. 76-17

F.T.M. Nieuwstadt and C.A. Engeldal

Application of the recommended national air pollution model of the Netherlands to the NATO common data base for the Frankfurt area

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SUMMARY

The national air pollution model of the Netherlands, which is extensively described in this report, has been applied to the NATO/CCMS data base for the Frankfurt region. With this model the annual averaged concentration has been calculated. A distinction was made between the contributions due to area source emissions and those due to point source emissions. The results for the annual averaged concentration are presented in the form of isopleth maps and are also given for six specified receptor locations. The calculated concentrations are compared with preliminary results, which were presented at the meeting of the NATO/CCMS modeling panel in Quail Roost (September 1976).

-o-o-o-

INTRODUCTION

As part of the Practical Demonstration of Urban Air Quality Simulation Models in the NATO/CCMS air pollution study, the proposed national air pollution model for the Netherlands (Nieuwstadt et al., 1976) has been applied to the standard data base for SO_2 of the Frankfurt region, as given in the NATO/CCMS document M.P. 2/1975, 2.4.

The yearly averaged concentration has been calculated. Programs to calculate the frequency distribution have not yet become available.

The following remarks should be made regarding the use of the data base. The area sources, which originally had been of the dimension 500 x 500 m, were transformed to area sources of 1 x 1 km. The corners of these area sources were chosen so as to coincide with the grid points of the calculation grid of 1 x 1 km, the dimensions of which are in the W-E direction $9 \text{ km} < x < 48$ km and in the N-S direction $17 \text{ km} < y < 44$ km. The source height and the emission of an area source of 1 x 1 km were calculated from the data for the four original 500 x 500 m area sources. The area source emissions used in this calculation were obtained by multiplying the emissions given in the data base by a factor 1560/8760. This is the ratio of the number of yearly heating hours as given in the data base to the total number of hours in a year. For the height of the point sources the geometrical stack height of the data base was used, so that in the calculation no account was taken of the differences in terrain elevation. For the distribution function of wind speed, wind direction and stability classes the data based on the stability class definition by Klug ($h < 100$ m) were used, as given in the data base.

The calculations were performed with a total number of 540 area sources and 681 point sources on the B6700-computer of the Royal Netherlands Meteorological Institute. The total computer time for the calculation of the point sources was 39 min. and for the area sources 26 min.

DESCRIPTION OF THE MODEL

For the background on the choice of the national model and its parameters one is referred to Nieuwstadt et al. (1976) and to Kleine Commissie (1976).

1. The long-term Gaussian model

The concentration averaged over a long period (season, year) $\overline{C}$ [g/m^3] at ground level, as a result of a source at the location: (0,0,H), is described by

$$\overline{C}(x,y) = \sum_S \sum_N \left\{ \frac{2Q}{\sqrt{2\pi}\, u_N\, \sigma_{z_S}} \cdot f(\theta,S,N)\, \frac{n}{2\pi r} \cdot C_{L_S} \cdot \exp\left(-\frac{H^2_{S,N}}{2\sigma^2_{z_S}}\right)\right\}$$

In this equation r[m] is the horizontal distance from the source: $r = \sqrt{x^2 + y^2}$. The source has an emission Q[g/s].

The concentration is given in a sector $2\pi/n$ in width around the direction $\theta + 180^\circ$ (θ indicates the wind direction class, defined as a sector also $2\pi/n$ in width around θ).

The vertical dispersion coefficient σ_z [m] is classified according to stability classes (S).

The transport velocity of the plume u [m/s], calculated from the wind speed, is subdivided into wind speed classes (N). H [m] is the effective source height, which follows from the physical stack height h [m] and the plume rise Δh [m]. The function $f(\theta,S,N)$ gives the distribution over the wind speed, wind direction and stability classes. The coefficient C_{L_S} describes the influence exerted on the ground level concentration by the mixing height (8).

2. Stability classes (S)

To determine the stability class the KNMI-scheme, which is a modification of the Pasquill stability class definition, is chosen. The stability class is defined from the amount of clouds (in eights), the wind speed at a height of 10 m (in knots, 1 knot =

½ m/s), the time of the day and the season (Nieuwstadt et al., 1976).

The dispersion coefficients for high sources are classified after the stability class definition by Singer and Smith.
A tentative relation between the stability classes after the KNMI-definition and after the Singer and Smith definition is

KNMI		Singer and Smith
A	—	B_2
B	—	B_2
C	—	B_1
D ($u \leqslant 5.5$ m/s)	—	B_1
D ($u > 5.5$ m/s)	—	C
E	—	D
F	—	D

where u is the wind speed at a height of 10 m.

The results based on the stability class definition by Klug ($h < 100$ m) have been used in the calculations with the data base. The following relation between the Klug stability classes and the KNMI/Pasquill classes was chosen:

KNMI		Klug
A	—	V
B	—	IV
C	—	III_2
D	—	III_1
E	—	II
F	—	I

3. The distribution function of wind direction classes, stability classes and wind speed classes $f(\theta,S,N)$

The distribution function consists of a frequency distribution over 6 stability classes S (2), 3 wind speed classes N and 12 wind direction classes θ of the size of $2\pi/n = 30^\circ$ (345°-015°, 015°-045° etc.). This distribution function was calculated from the meteorological data given in the data base.

For the 3 wind speed classes the representative wind velocity at a height of 10 m is defined as

Wind speed class	Wind speed limits	Representative wind speed
1	1- 5 kts (0.5-2.5 m/s)	1.45 m/s
2	6-11 kts (3-5.5 m/s)	4.0 m/s
3	$\geqslant$ 12 kts ($\geqslant$ 6 m/s)	8.0 m/s

4. Dispersion coefficients (σ_z)

The dispersion coefficients are a function of the height above the earth's surface, because the turbulence on which the dispersion coefficients depend is a function of the height above the surface. The recommendation for the dispersion coefficients is therefore subdivided according to the effective source height H.

a) Low sources ($H \leqslant 10$ m) and area sources.

σ_z according to Pasquill

$\sigma_z = ar^b * C_{z_0}$ (σ_z and r in m)

Stability class	a	b
A	0.28	0.90
B	0.23	0.85
C	0.22	0.80
D	0.20	0.76
E	0.15	0.73
F	0.12	0.67

The coefficient C_{z_0} describes the effect of the surface roughness on the dispersion coefficient. The roughness of the area where the source is situated is characterized by the roughness length z_0[m].

For z_0 = 0.10 m it follows that $C_{z_0} = 1$. For other values of z_0 the coefficient C_{z_0} becomes

$$C_{z_0} = (10\ z_0)^{0.53}\ r^{-0.22}$$

z_0[m] is the roughness length and r[m] the horizontal distance from the source (1).

Some representative values for z_0 are

flat country	(e.g. polder landscape with a few trees)	approx. 0.03 m
agricultural land	(e.g. airfield, arable land, polder with many trees)	approx. 0.10 m
cultivated land	(e.g. hothouse area, open area with much vegetation, scattered houses)	approx. 0.30 m
residential area	(e.g. area with many but low buildings, wooded area, industrial area with not too high obstacles)	approx. 1.00 m
urban area	(e.g. a big city with high buildings, industrial area with high obstacles)	approx. 3.00 m

For the calculations with the data base for the Frankfurt area the value of the roughness length is taken to be z_0 = 3.00 m.

b) High sources ($100 \leq H <$ circa 400 m).

σ_z according to Singer and Smith

$\sigma_z = ar^b$ (σ_z and r in m)

Stability class	a	b
B_2	0.411	0.907
B_1	0.326	0.859
C	0.223	0.776
D	0.062	0.709

c) Sources with an effective height $10\ m < H < 100\ m$.

The σ_z is determined for each value of r by means of a linear interpolation:

$$\sigma_z = \sigma_z(a)(100-H)/90 + \sigma_z(b)(H-10)/90$$

where $\sigma_z(a)$ is the σ_z calculated according to a) and $\sigma_z(b)$ is the σ_z calculated according to b).

d) Very high sources ($h \geqslant 150$ m and $H >$ approx. 400 m).

An effective height > 400 m was reached by three point sources in the data base. This occurred only for the lowest wind speed class. The calculation of the concentrations from these point sources has been done with the coefficients of Singer and Smith.

5. <u>Plume rise (Δh)</u>

The plume rise is calculated with formulas of Briggs.

$$\Delta h = 109\ Q_H^{3/4}/u \qquad Q_H < 6\ MW$$

$$\Delta h = 143\ Q_H^{3/5}/u \qquad Q_H \geqslant 6\ MW$$

The Q_H is the heat output of the sources in MW. The u is the wind velocity at the top of the stack (h) (calculated by means of the equation given in 7).

An upper limit to the plume rise is set by the equation

$$\Delta h = 115(Q_H/u)^{1/3}$$

This equation results from the plume rise formula of Briggs for stable conditions, with the temperature gradient parameter s equal to $1.4\ 10^{-4}$.

The Q_H is calculated with respect to an air temperature of 10° C.

6. Transport velocity (u)

The transport velocity of the plume must be representative of the entire layer in which the diffusion takes place. This velocity is calculated from the representative wind speed at a height of 10 m (u_{10}) for each wind speed class N (3). From the wind speed u_{10} the wind velocity u(z) at an arbitrary altitude z can be calculated by means of the equation given in 7.

In the calculation of the transport velocity a classification is applied after the effective source height, analogous to the classification of the dispersion coefficients (4).

a) Point sources ($H \leqslant 10$ m): the wind velocity at a height of 10 m: u_{10}.

Area sources: the wind velocity at the effective source height H (with a minimum of H = 10 m): u(H).

b) (100 m $< H <$ approx. 400 m).

I.	$H \leqslant \frac{1}{2}L$	$u = u(H)$	if $0.62\ \sigma_z \leqslant H$
		$u = u(0.62\ \sigma_z)$	if $H \leqslant 0.62\ \sigma_z \leqslant \frac{1}{2}L$
		$u = u(\frac{1}{2}L)$	if $0.62\ \sigma_z > \frac{1}{2}L$
II.	$H > \frac{1}{2}L$	$u = u(H)$	
		in the case of $L \leqslant H \leqslant 3/2\ L$: $u = u(L)$	

The σ_z is calculated according to 4b. The mixing height L is discussed in 8.

c) ($10 \leqslant H \leqslant 100$ m).

For all distances the transport velocity u is determined by a linear interpolation.

$$u = u(a)(100-H)/90 + u(b)(H-10)/90$$

where u(a) is the transport velocity calculated according to a) and u(b) is the transport velocity calculated according to b), with σ_z following from 4b and with H chosen equal to 100 m.

7. Wind profile according to a power law

The wind speed at an arbitrary height z [m] is calculated from the wind speed at a height of 10 m: u_{10} by means of the equation

$$u(z) = u_{10} (z/10)^p$$

The exponent p is a function of the stability class.

Stability class according to Pasquill	p
A	0.10
B	0.10
C	0.16
D	0.16
E	0.30
F	0.30

8. Mixing height

The mixing height sets a limit to the vertical dispersion. For each stability class one fixed mixing height is chosen.

Stability class according to Pasquill	L (in m)
A	1500
B	1500
C	1000
D	500
E	200
F	200

The influence of the mixing height on the ground level concentration is determined by the coefficient C_{L_S} (1).

	C_{L_S}
$0 < \sigma_z/L \leqslant 0.6\sqrt{1-H/L}$	1
$0.6\sqrt{1-H/L} < \sigma_z/L < 0.9$	$1+\left[\exp\left\{\frac{(2L-H)^2}{2\sigma_z^2}\right\}+\exp\left\{\frac{(2L+H)^2}{2\sigma_z^2}\right\}\right] \Big/ \exp\left\{-H^2/2\sigma_z^2\right\}$
$\sigma_z/L > 0.9$	$\frac{1}{L}\,\frac{\sqrt{2\pi}\,\sigma_z}{2\exp(-H^2/2\sigma_z^2)}$

This last factor leads to the so-called uniform vertical distribution of the concentration in the mixing layer. In the evaluation of C_{L_S} the σ_z is calculated according to 4a, b or c.

When $h > L$ holds good, it is assumed that the plume is above the mixing layer and for that reason will not contribute to the concentration at ground level.
It is also assumed that for $H > 3/2\ L$ the plume will break through the inversion capping the mixing layer and will not contribute to the ground level concentration either. When $L \leqslant H \leqslant 3/2\ L$, the effective source height H is set equal to the height of the mixing layer L.

9. Area sources

An area source is for practical reasons subdivided into squares with a side of 1 km.
To calculate the dispersion from an area source the virtual point source equation is used. The virtual point source is situated in the middle of each square of the area source. The ground level concentration from each virtual point source is calculated with the equation

$$\overline{C} = \sum_S \sum_N \left\{ \frac{Q\ f(\theta,N,S)}{u_N\left(\sqrt{\frac{\pi}{2}}\ \sigma_{z_S}\ \frac{2\pi r}{n} + \frac{A}{K}\right)}\ C_{L_S}\ \exp\left(-\frac{H^2_{S,N}}{2\sigma^2_{z_S}}\right)\right\}$$

For an explanation of most of the parameters used in this equation see section 1.

The emission Q is the total emission [g/s] of the area source square. The initial vertical dispersion inside the area source is simulated by adding a virtual distance r_o [m] to the horizontal distance r [m] in the evaluation of σ_z: $\sigma_z(r + r_o)$.

The virtual distance r_o is determined from the equation $\sigma_z(r_o) = H$, where H is the effective source height of the area source and where the σ_z for each stability class is calculated according to 4a, b or c, the roughness correction included.

The initial horizontal mixing inside the area source is described by the term A/K in the denominator of the above equation. The A [m^2] is the area of the area source.
The factor K is a function of the size of the area source square. For a square of 1 x 1 km K can be chosen equal to 50.
The virtual point source model should not be used for calculating the ground level concentration inside the area source square.

RESULTS

In the figures 1, 2 and 3 isopleths of the annual averaged concentration are given for the concentrations respectively from the point sources, area sources and both groups combined.

In the receptor points the following concentrations have been calculated.

	Receptor points		Concentration in $\mu g/m^3$		
	x-coord.(km)	y-coord.(km)	point source	area source	total
1 :	22.29	26.53	21.0	57.5	78.5
2 :	28.25	28.15	17.0	48.1	65.1
3 :	24.76	28.98	20.8	67.5	88.3
4 :	16.00	27.00	28.8	41.3	70.1
5 :	19.00	32.00	15.3	29.5	44.8
6 :	34.00	27.00	11.7	29.7	41.4

No comparison with measured data could be made, because the measuring results will be available only at a later stage of the demonstration.

Some comparison with other calculations could be made, the preliminary results of which were given at the meeting of the modeling panel in Quail Roost, in September 1976.

Receptor points	1976 Tex. Air Contr. Brd			1976 Turner			1976 Irwin			this study		
	I	II	III	I	II	III	I	II	III	I	II	III
1	14	109	123	16	55	71	4	68	72	21	58	79
2	13	84	97	15	45	60	4	53	57	17	48	65
3	16	95	111	16	60	76	3	72	75	21	67	88
4	15	70	85	14	39	53	3	44	47	29	41	70
5	15	8	23	13	17	30	2	19	21	15	30	45
6	8	43	51	11	26	37	2	36	38	12	30	42

I concentrations from the point sources in $\mu g/m^3$
II concentrations from the area sources in $\mu g/m^3$
III total concentration in $\mu g/m^3$

From Turner (1976) only the results for CDM-36 were compared. In the results of Irwin (1976) the comparison was made with the average over the five samples.

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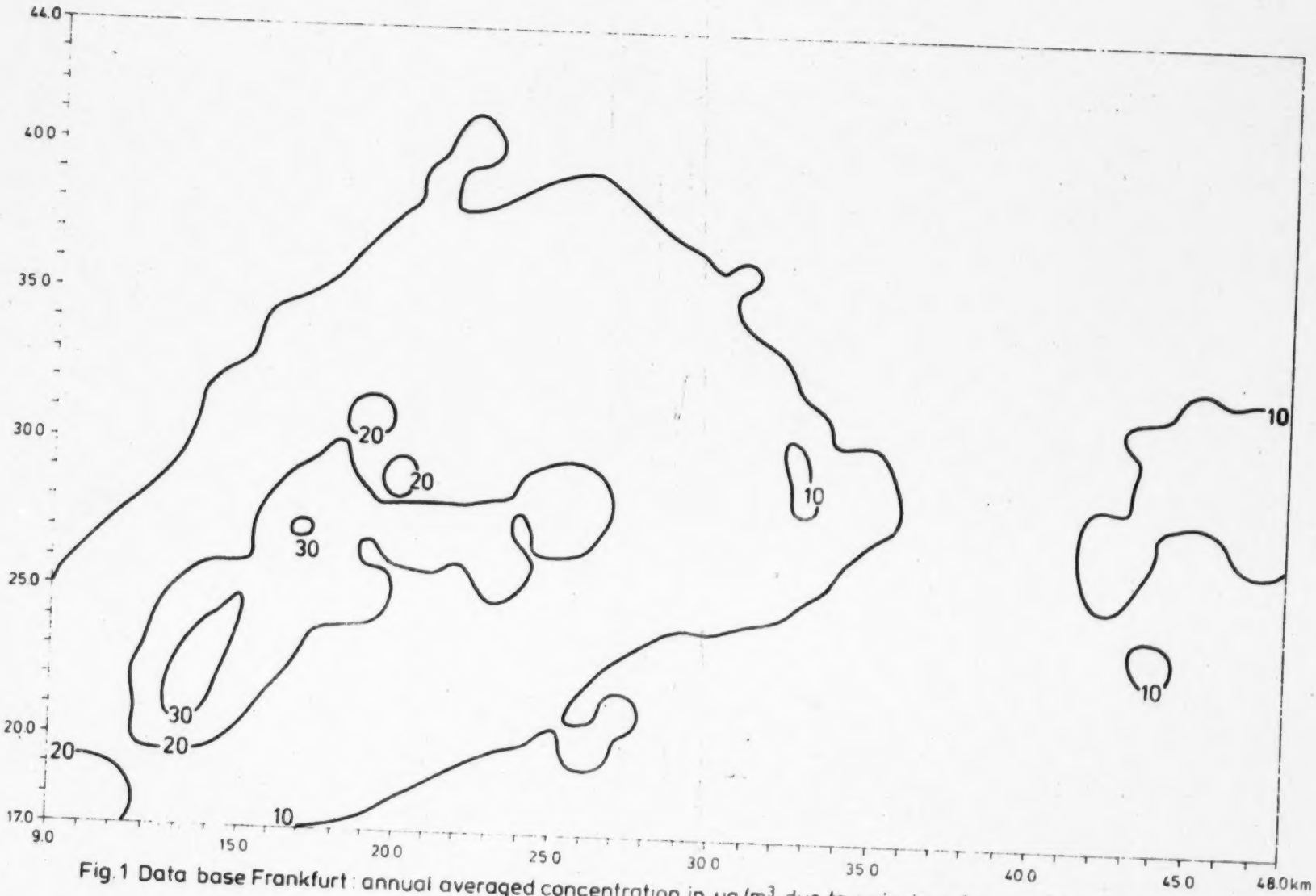

Fig. 1 Data base Frankfurt : annual averaged concentration in $\mu g/m^3$ due to emissions from point sources

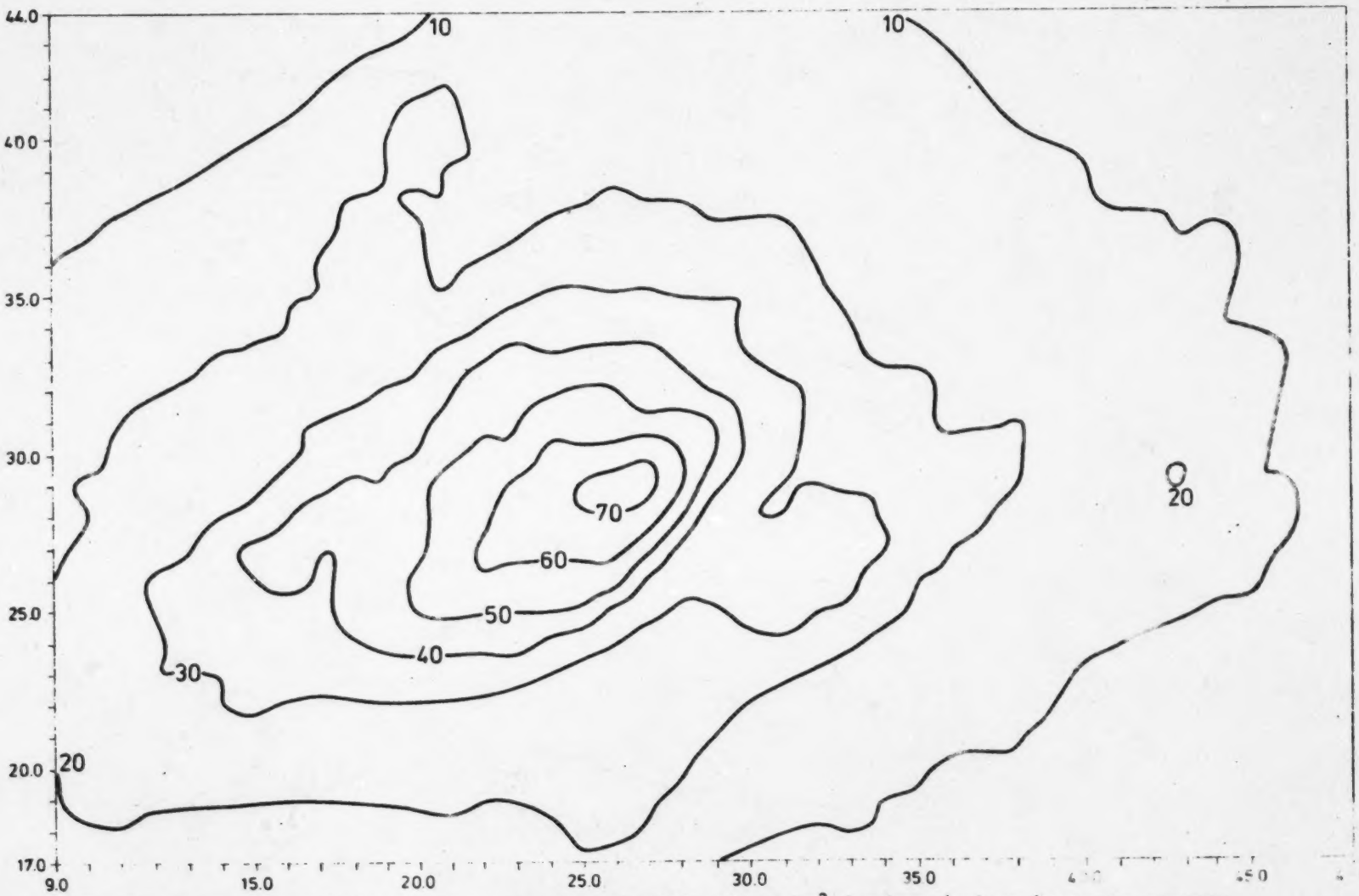

Fig. 2 Data base Frankfurt: annual averaged concentration in $\mu g/m^3$ due to emissions from area sources

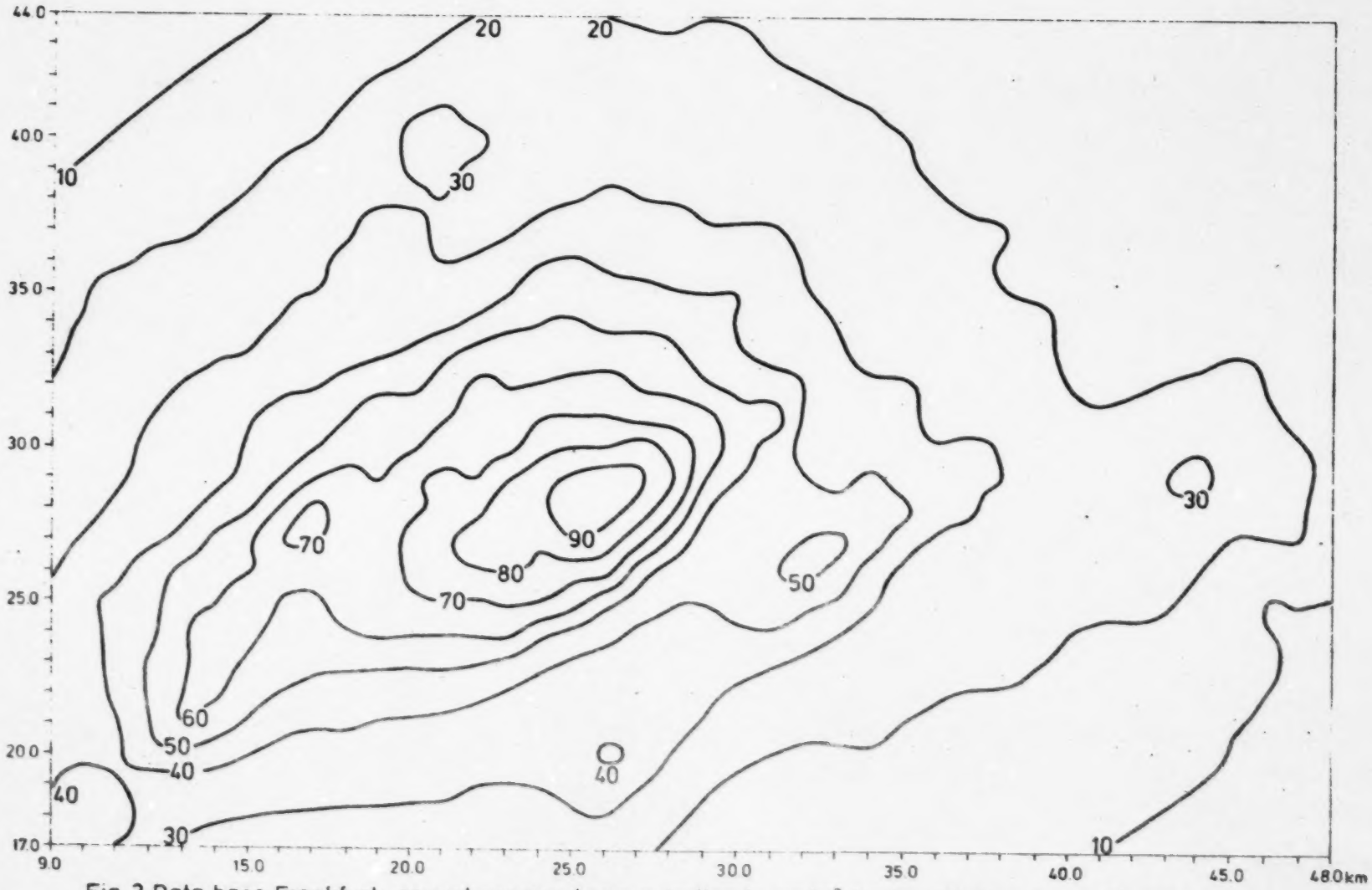

Fig. 3 Data base Frankfurt: annual averaged concentration in $\mu g/m^3$ due to emissions from all sources

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Santomauro, Tebaldi, Bellotti, Gualdi;
Italy (ATDL/Milano)

OSSERVATORIO METEOROLOGICO DI BRERA

ISTITUTO DI METEOROLOGIA APPLICATA

Via Brera 28 MILANO (Italy)

L. SANTOMAURO

G.TEBALDI G.BELLOTTI R.GUALDI

APPLICATION OF THE DIFFUSION MODEL OF MILAN (ITALY) METROPOLITAN AREA TO THE NATO COMMON DATA BASE FOR FRANKFURT AREA

Milano - February 1977

1) INTRODUCTION

The study aim is the one of simulating Frankfurt atmosphere dynamic behaviour, with regard to SO_2 ground concentration, by means of the mathematical model applied to Milan area.
In this application has been made use of the set of emissions informations concerning the years 1970-71 and the set of meteorological parameters concerning the period 8/1971 - 7/1972, sent by NATO/CCMS Pilot Study Air Pollution.
On the base of these informations we have calculated the SO_2 ground concentration for a yearly period, calculating apart the concentrations due to area source, the point ones and the total amount. For every elaboration we have drawn the isophlets.

2) ALGORITHMS DESCRIPTION

The mathematical model chosen to simulate the SO_2 diffusion for Milano metropolitan area is the ATDL model. It considers separately individual point sources as tall stacks and lumping the contribution of the multitude of lesser sources of all types, these last are collected into a spatially variable area-source concentration. This is assumed to satisfy the steady-state diffusion equation in two indipendent variables (Gifford F.A. Jr and Hanna S.R. - 1970):

$$u(z)(\partial X_1/\partial x) = (\partial/\partial z)\, K(z)\, (\partial X_1/\partial z) \qquad (1)$$

where the mean wind, u(z), blows in the x-direction.
Neglect of the y component of the diffusion is equivalent to the observation that point-source plumes in the atmosphere

tend to be long and narrow, and so the concentration at a point can be influenced only by sources in a narrow, plume-shaped upwind sector. If u and the vertical eddy-diffusivity, K, are assumed to obey the following usual power laws:

$$u(z) = u_1 (z/z_1)^m \qquad (2)$$

$$K(z) = K_1 (z/z_1)^n \qquad (3)$$

the partial solution to Eq. (1) for the ground level concentration distribution, χ_{10}, due to an area-source is (Gifford F.A. jr - 1970):

$$\chi_{10} = \left[z_1^{\,m} / c_1 u_1 B (1-s) \quad (\tfrac{1}{2}\Delta x)^{1-s} \right] \cdot$$

$$\left[Q_1(0,0) + \sum_{i=-4}^{4} \sum_{j=-4}^{4} Q_j(i,j) f(i,j) \left[(2i+1)^{1-s} - (2i-1)^{1-s} \right] \right] \qquad (4)$$

where

$$s = (m+1)/(2+m-n) \qquad (5)$$

and the distance, x, from the receptor point (it is assumed to be located at the center of a source square) to the upwind edge of the city is given by

$$x = (N + \tfrac{1}{2})\Delta x \qquad (6)$$

N is the number of upwind grid squares in the source inventory, Δx is the grid size. Q is the source strength and it is constant for each grid-square. The parameter B depends on the vertical concentration distribution

$$B = \int_0^\infty \xi \, f(\xi) \, d\xi \qquad (7)$$

where

$$\xi = z/Z$$

where Z is the reference height, viz, it represents the "top" of the polluted air. and increases with distance from the upwind edge according to

$$Z = C_1 x^{1/(2+m-n)} \qquad (8)$$

The total concentration distribution X_A is related to the ground-level value. X_{AO}, by:

$$X_A = X_{AO}(x) \, f(z/Z) \qquad (9)$$

The constant C_1 is determined from the relation

$$C_1 = 3a^{1/(m+1)}$$

where a is defined by the power-law formula for the standard deviation of the vertical concentration distribution

$$\sigma_z = a x^b \qquad (10)$$

and

$$Z \simeq 3\sigma_z$$

Values of a and b have been summarized in the Table 1 and they are based on the values given by Smith (Smith M.E. 1968) and includes also the Gifford and Hanna estimate of the value corresponding to Pasquill's type D condition.

TABLE 1

	a	b	(1-b)	a(1-b)
Very unstable	0.40	0.91	0.09	0.036
Unstable	·33	·86	·14	0.46
Neutral	22	80	20	0.44
"Pasquill" - D	15	75	25	0.38

(from Gifford and Hanna - 1970)

For the stable conditions the values of a and b estimated for Milano area, respectively, 0.13 and 0.74, consequently (1-b) = 0.26 and a(1-b) = 0.034.

To estimate SO_2 surface concentrations due to point, or individual, sources it is used the Gaussian plume formula:

$$X = \frac{1}{\left(\frac{\Delta x}{2}\right)^2} \int_0^{2\pi} d\theta \int_0^{\Delta x/2} \sqrt{\frac{2}{\pi}} \frac{Q_p}{a r^{1-b} u 2\pi} \exp\left(-\frac{H^2}{2a^2 r^{2b}}\right) dr \qquad (11)$$

where: Q_p is the point source strength, and H is the effective stack height, the others symbols are those usually used.

3) METEOROLOGICAL INPUTS

The ATDL model calculates the ground concentrations according to the emissions and to the meteorological conditions: wind speed (ms^{-1}), frequency distribution of wind direction, coming from 16 sectors of compass, and Pasquill stability classes. The averages concerning the wind speed and direction are calculated on the bases of three-hourly values derived from the Frankfurt data-base. The results (fig. 1) show a mean wind speed equal to 3.0 m s^{-1} and a prevailing wind direction coming from the opposite sectors NE and SW. Since the SO_2 concentrations are referred to the whole year the neutral stability class we have used. The diffusion coefficients are show in tab. 1.

4) EMISSIONS INVENTORY

The area interested by this study is the one drawn for Frankfurt (26 x 39 km) delimited by coordinates 5568-5543 and 3460-3948.
The original grid pattern with size of 500 m has been extended to 1000 m. assembling four adjacent squares with an amount of 914 squares.
The ATDL model considers the recentor point placed in the center of each square. as well as the point sources.
The area sources. grouping in a sole factor both the heating sources and the set of small sources. has been derived from the original grid pattern. where are considered as point sources. transforming the emissions strenght from Kg h^{-1} to $\mu g\ m^{-2}\ s^{-1}$.

The yearly averages of emissions have been obtained multyplying each emission value by the factor 0.178: that is the ratio between the heating hours number and the ones contained in the whole year.

For what is concerning the point sources, to satisfy the model structure, they have been grouped in 16 classes (tab. 2) leaving out the contribute of the ones outside the grid pattern.

The geometric height of the stacks is refered to ground level; the yearly emissions value has been transformed from $Kg\ h^{-1}$ to $\mu g\ sec^{-1}$.

The Δh has been calculated by the CONCAVE model performing a weighted means for each height class.

TABLE 2

Classes	h_s(m)	$\bar{h}_s$ (m)	No of stacks
1	1-9	8	40
2	10-11	11	40
3	12-14	13	50
4	15-16	16	48
5	17-18	18	48
6	19-21	20	52
7	22-24	23	45
8	25-27	26	54
9	28-32	30	59
10	33-40	35	50
11	41-50	45	30
12	51-75	75	28
13	76-100	100	28
14	101-135	125	12
15	136-150	150	6
16	> 150	200	7
			614

Note: The $\bar{h}_s$ is the weighted mean of stacks height for each class.

5) RESULTS

The elaboration has been performed by means of the IBM 370/135 computer provided with 192 K of real memory and with virtual memory. The model has been programmed by FORTRAN IV language; the memory amount necessary to this elaboration is:

MAIN PROGRAM: 2D2DE hexadecimal

WHOLE PROGRAM: 7F64F hexadecimal

The elaboration time is $15^{m}\ 4^{sec}$

In the figures 2,3, 4 are drawn the isophlets of the yearly concentration for every calculation.

The concentrations ($\mu g\ m^{-3}$) in the recentor points are detailed by the originals outputs of the computer (see appendix). The values printed are grouped in eight columns starting by ones of receptor point with coordinates 5567-3460. The real distribution of concentrations is obtained copying the values from the first square of the first row prosecuting row by row till to complete the whole grid pattern.

6) REFERENCES

Gifford F.A. Jr Hanna S.R.	Urban Air Pollution Modelling. Paper ME-320 2nd Int. Clean Air Congress. Washington - Dec. 11 (1970)
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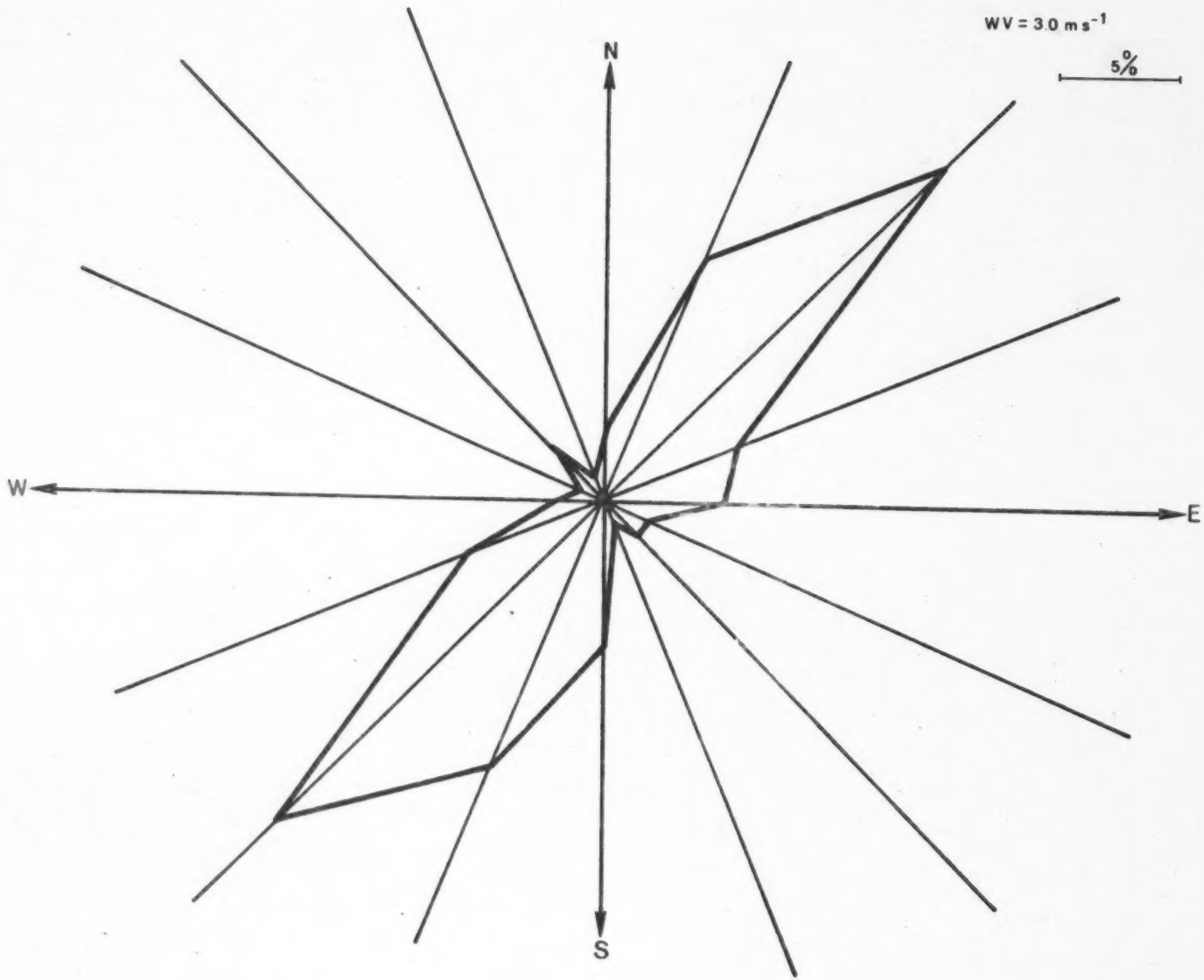
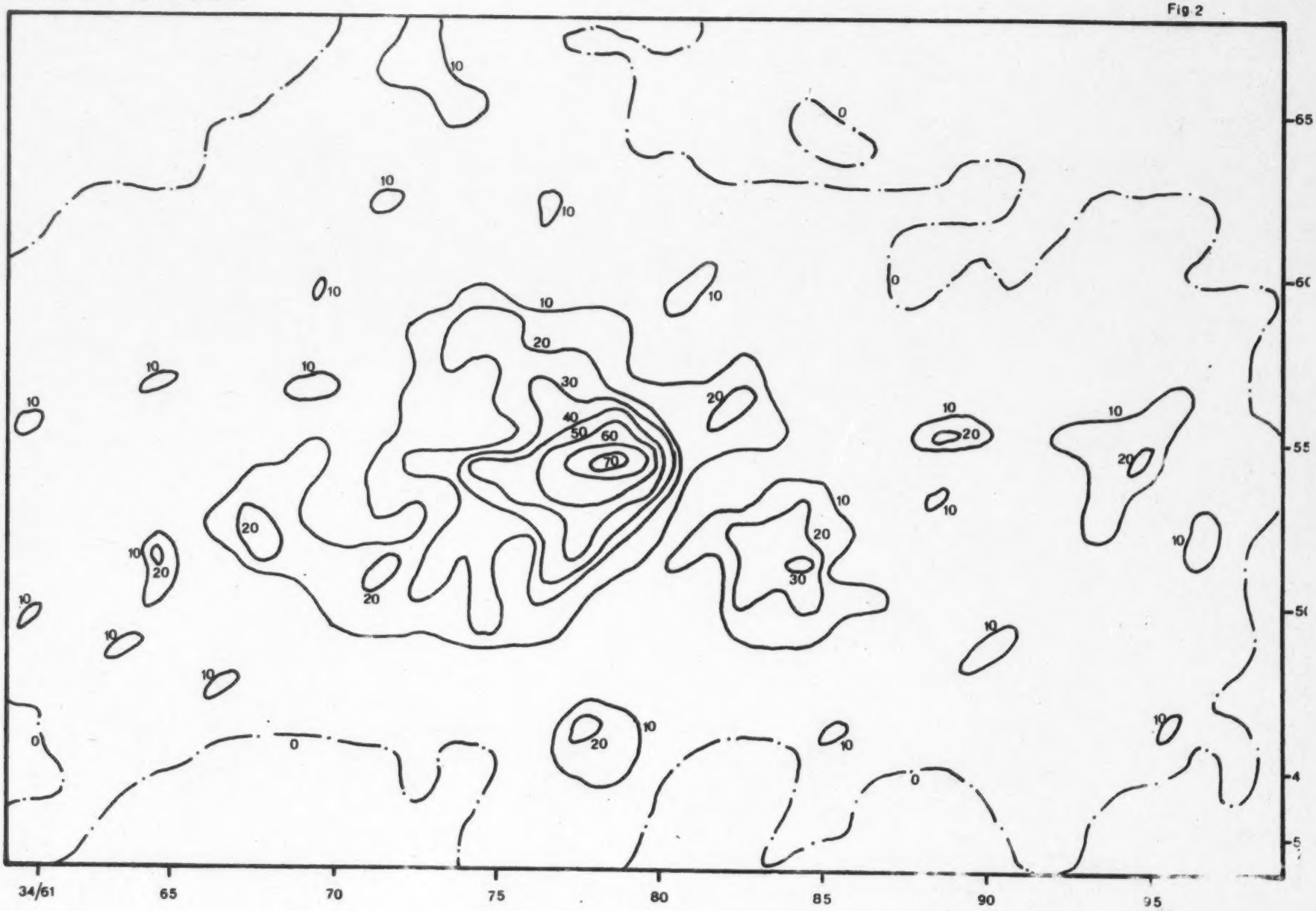
Fig.1

FRANKFURT: WIND DISTRIBUTION



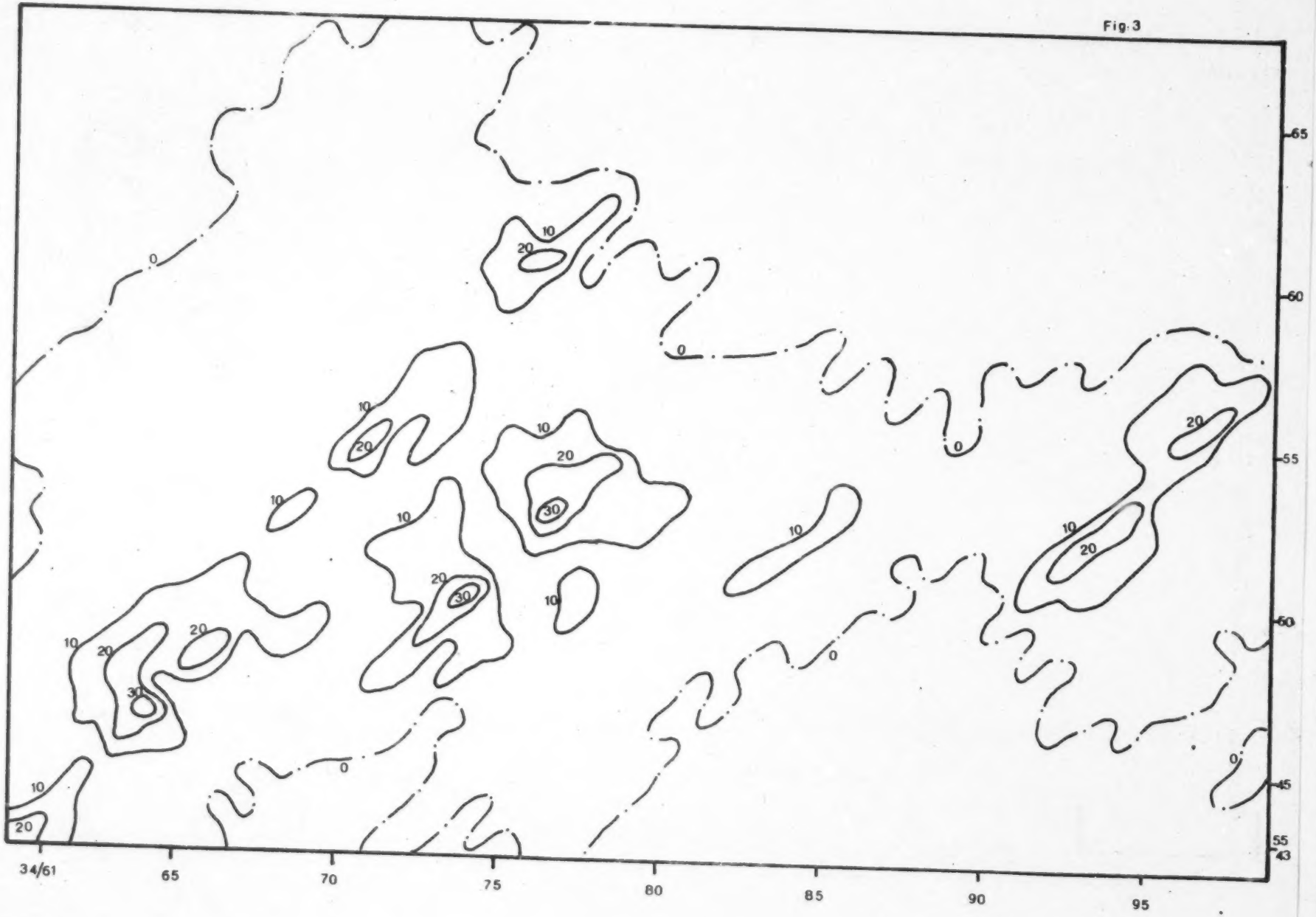
FRANKFURT: AREA SOURCES

Fig 2



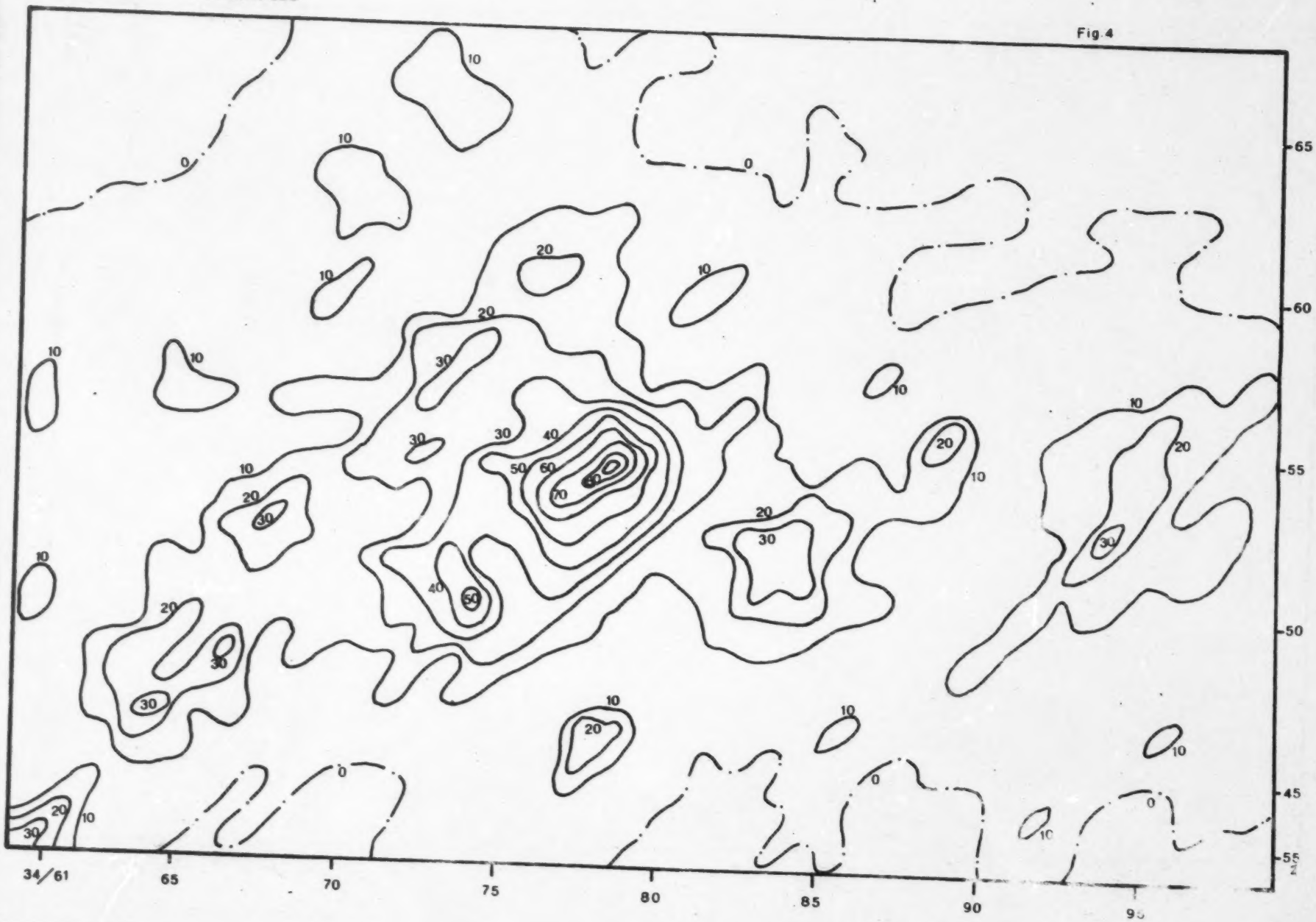
FRANKFURT: POINT SOURCES

Fig. 3



FRANKFURT : ALL SOURCES

Fig.4



APPENDIX

1) - CONCENTRATIONS FROM GROUND SOURCES

2) - CONCENTRATIONS FROM ELEVATED SOURCES

3) - CONCENTRATIONS FROM ALL SOURCES

4) - RATIO OF CONCENTRATION DUE TO AREA SOURCES TO TOTAL CONCENTRATION

CONCENTRATIONS FROM GROUND SOURCES

CONCENTRATIONS PATTERN

0.0	0.0	0.C	0.0006	0.0027	C.0149	0.0262	0.0537
0.1313	0.4114	2.4155	6.8091	9.7716	1.6110	3.1714	5.0949
C.5608	0.2670	0.4264	5.0562	2.6507	0.1121	0.0259	0.0414
0.0188	0.0347	0.C451	0.0157	0.0393	0.0019	0.0058	0.0038
0.0115	0.0061	0.0182	C.0	0.0	0.0	0.0	0.0010
0.0010	0.0061	0.C045	0.0132	0.0230	0.0544	0.1186	0.2322
0.7710	2.0336	12.7386	13.8926	6.1693	1.6936	1.0785	0.5606
0.5820	0.6286	0.4095	0.3260	0.0578	0.0819	0.0179	0.0514
0.0815	0.0677	0.C770	0.C197	0.0695	0.0380	0.0797	0.0324
C.1038	0.0197	0.0356	0.0048	0.0583	0.0088	0.0103	0.0204
0.0284	0.0567	0.0595	C.1148	0.1506	0.2845	0.6294	1.2685
1.9749	6.0303	6.1538	10.6898	8.9007	0.8837	2.8920	5.4902
0.4488	0.3230	0.2240	C.1532	0.1269	0.0919	0.9593	0.2303
0.1405	0.0638	0.C830	0.0820	0.1203	0.0647	0.1188	0.0482
C.0570	0.0126	0.C926	0.C248	0.0401	0.0196	0.0599	0.1005
0.1165	0.2129	0.2482	C.4716	0.8723	1.2488	4.5159	1.9085
2.0090	2.2052	6.8545	5.6287	3.9472	0.8128	0.6414	0.6221
C.4154	0.3612	0.2407	C.1858	0.2435	1.0644	2.0777	0.1258
C.1062	0.1078	0.1431	C.1983	0.2215	0.0725	0.0786	0.1285
C.1600	0.1277	0.1058	0.1369	0.0409	0.0873	0.2537	0.3357
0.3016	0.4290	0.4997	C.5832	2.2890	9.1834	7.2370	2.0604
1.4955	1.1989	0.8674	C.8002	1.6427	1.0384	0.9550	2.4004
C.4941	0.3346	0.4515	C.3305	0.4772	0.2654	0.1993	0.2056
0.1963	0.7547	1.5810	0.1844	0.1093	0.2679	0.3228	0.2259
C.2307	0.1976	0.1078	0.0863	C.4204	1.7026	1.1202	0.5753
C.6189	0.6953	1.0929	1.3150	5.6977	8.2077	8.5192	1.2349
C.8346	0.8935	1.2253	9.6773	2.8614	3.3560	0.9287	0.7244
0.7847	0.7032	0.5947	C.4887	1.5183	1.0816	1.6333	1.0844
4.5990	1.4880	0.1337	C.2495	3.7434	0.5764	1.0233	0.9162
C.3859	0.0631	0.4439	3.7414	3.2305	1.6132	4.6246	2.6454
2.8525	2.2318	1.5231	6.2318	2.5901	4.3491	0.9904	1.8171
4.1234	4.7903	6.5563	2.1022	5.6311	1.2549	4.9785	5.7675
1.2120	0.3677	1.2637	1.9010	1.0165	C.3112	0.4129	0.3224
0.3230	0.2439	0.4861	0.4878	2.2610	1.7866	0.4898	0.3126
0.0725	0.6223	2.8780	5.6752	3.0943	4.7684	8.9696	2.8948
4.0207	1.2296	2.2431	6.0425	4.3176	1.1040	1.6022	6.7881
5.1002	8.0784	2.8776	5.2667	2.0327	4.3146	9.3976	2.3604
0.4920	0.6032	0.4931	0.4660	0.3528	0.2384	0.4724	0.3798
1.4815	2.6186	2.3812	6.8087	0.6079	0.2038	0.2523	0.1576
2.3889	2.7807	1.0626	1.0150	1.9432	1.8154	2.5877	1.2105
1.3534	8.9580	2.5204	0.9566	5.1606	3.1206	8.4738	5.1824
7.4827	4.7315	4.3168	6.3577	12.3479	4.1364	1.3558	1.2390
0.6053	0.7082	0.5109	0.4052	C.5659	2.8946	2.0306	0.5531
0.9679	0.9324	5.6272	0.4559	0.5683	0.4684	0.4695	0.6427
C.8260	1.7852	4.3901	1.1589	1.0674	1.1390	5.0514	2.4578
2.2828	1.7792	1.6580	14.9594	18.6597	22.7237	21.6828	10.2641
5.6746	11.7826	4.4304	5.1274	4.8483	2.6932	2.0700	1.1314
0.8322	0.8846	0.8807	0.6853	1.4490	0.6958	0.7460	0.7590
C.8903	0.7643	0.8905	1.6479	3.7732	0.4102	1.9317	1.0968
2.2186	3.5663	4.9892	1.1952	1.4671	6.5760	2.1672	1.5289
1.5682	2.3064	8.9629	20.0470	11.9099	23.7636	24.9376	24.3545
12.8510	5.3073	5.3561	6.1510	13.8742	2.6136	1.2036	2.7780
8.3749	1.4817	2.7078	C.7750	1.1067	1.2608	0.9378	1.5439
1.3423	2.3131	1.3289	C.8568	0.3559	7.3007	2.8946	0.9316
3.3906	9.5093	3.1547	6.8470	6.0697	8.6860	9.5219	2.2288
6.5532	14.0130	13.5048	9.5103	26.3416	28.6845	22.7960	22.8582
9.8164	17.7120	8.1818	22.C862	3.7545	1.5954	6.5872	5.0001
1.2663	2.0848	2.1804	1.4706	2.2176	4.0409	7.0842	5.7161
9.5276	1.4129	0.6978	C.3537	9.6980	.3.5768	1.0183	3.2590

4.3426	5.0853	7.2296	2.1321	3.0854	2.8911	4.2061	3.9810
14.5341	11.5777	10.5270	15.9232	26.4917	21.8295	52.2838	29.0328
9.6488	15.1291	10.4640	7.5346	2.6425	5.5386	2.0064	1.6771
17.6989	11.5133	1.4901	1.3160	12.3186	9.7436	13.3162	7.9209
1.6628	0.6283	0.5573	1.5278	5.9972	2.5348	2.6293	1.3846
1.9514	2.7461	2.1961	5.4484	12.1193	3.6775	15.0524	25.6891
13.2198	38.5008	20.7617	34.3102	60.5939	66.7344	59.1351	12.5568
14.1636	5.1726	13.3123	4.6147	4.8492	2.5601	6.2032	7.1627
5.9324	1.9166	2.9143	5.5596	8.4021	15.8242	7.8289	1.1273
2.4559	0.6891	0.6751	0.7883	0.7771	3.4721	1.1530	1.5888
5.5422	9.1150	16.1282	7.1053	3.2365	11.1223	8.7110	13.4500
24.1291	33.4975	45.2167	47.1735	46.6784	39.4781	5.7606	6.6968
4.1830	11.0273	17.3956	3.6445	7.7227	6.9352	9.9068	4.4048
2.4781	1.3432	2.6705	11.3748	6.5546	3.0733	3.6366	6.4697
0.6625	0.5637	0.5827	0.9327	1.2609	1.9300	2.5527	18.1261
24.4648	13.7239	4.5567	7.8780	6.7157	8.4748	22.5126	23.1701
20.0624	27.2030	38.0694	27.0065	7.9332	3.7285	11.7415	22.0662
18.4846	15.8158	12.1130	4.8866	2.1345	6.3352	1.4310	1.0978
1.3561	1.8451	9.9091	2.4153	4.4494	8.9945	3.2476	0.4248
1.3324	0.9855	1.2209	5.7743	16.5810	3.2904	6.0509	19.0490
10.5973	11.3438	10.5747	18.1328	17.1009	27.2266	17.5882	13.9779
31.6937	37.6162	11.6850	3.3169	12.5456	5.1219	21.4281	23.0728
25.1789	6.0544	2.4414	1.6207	1.2671	5.1144	1.5183	1.2882
1.6140	1.4334	5.5542	5.5747	10.1581	1.5157	0.3624	8.0237
3.6282	6.0588	1.9073	10.0592	5.4998	3.0257	3.0387	2.7119
12.6053	8.7203	17.1180	17.9275	13.4294	18.2244	13.2455	25.4173
8.7917	5.2983	4.2529	2.5716	7.3474	23.0079	11.3487	17.0841
10.7461	10.8098	1.3053	0.7909	2.5064	2.2698	1.3966	0.8127
0.9410	1.6584	2.3908	1.0184	0.6598	0.3794	8.6386	4.1010
3.6967	1.9951	2.3352	12.0768	2.0499	1.8180	1.8106	5.4828
9.8226	11.9214	10.4302	8.6683	25.2597	10.7360	11.8953	6.7964
1.7706	1.8089	2.3913	3.5164	9.3311	10.1440	8.9674	4.2187
7.0026	1.0562	1.0055	3.9357	8.9598	0.9274	0.7390	0.7672
0.8672	5.0162	1.7418	3.5908	0.5740	0.8788	0.8910	3.4926
11.0729	3.6482	1.4619	5.0352	1.5707	1.4652	1.7553	2.3718
2.1119	2.2143	3.0431	3.2187	2.1534	1.9427	1.4110	1.3726
1.8870	2.3001	2.3359	2.0141	1.7283	1.4335	1.1411	1.1828
1.0555	4.4324	11.2152	4.9907	0.6115	0.5898	0.7497	1.3586
4.3747	1.1307	5.5268	0.2432	0.5283	0.7056	1.1153	2.9283
1.2355	2.8985	9.8886	2.4189	1.0375	1.2307	1.0432	1.0651
1.5240	1.7574	1.0816	1.1770	0.9745	1.3741	2.3444	2.2786
1.8614	1.5160	1.1118	0.8208	2.8384	1.7020	3.2459	2.0984
2.9528	1.7853	0.6129	0.6755	0.8400	0.6941	0.6293	0.9524
0.8459	0.3878	0.2581	0.4199	1.8029	0.9856	3.2033	5.5173
2.2609	6.5166	0.6941	0.5451	0.4968	0.5257	0.7128	0.6701
0.7438	0.7766	0.6024	3.3568	16.5658	13.9970	4.8537	1.6704
0.8416	0.8508	0.6319	3.6543	11.1941	5.0455	1.1498	1.5901
3.2899	0.5902	6.4052	3.6405	0.5099	0.8103	9.3303	0.5918
0.5663	0.3538	0.3859	1.4946	2.3402	0.8294	0.7178	0.6820
0.4438	0.2455	0.2099	0.2013	0.4171	0.1737	0.5196	0.3997
0.4292	0.6718	3.2709	13.2214	15.1518	6.5323	0.7380	0.3919
[illegible]	0.3871	1.0178	2.3722	0.8631	0.4805	0.6003	3.7192
0.6559	[illegible]	0.9737	0.5761	0.7586	0.5091	0.3442	5.6569
0.2949	0.3243	[illegible]	1.8764	0.5786	0.3051	0.2436	0.1060
0.0492	0.0545	0.0441	0.0435	0.2204	3.5958	0.1882	0.2813
0.8273	1.7361	5.6731	5.7897	1.0783	0.4436	0.2164	0.1855
0.4545	1.1630	0.7627	0.4105	0.3756	0.3866	0.4410	1.1934
3.7311	1.2917	0.6486	0.3094	0.1880	0.3940	3.4038	0.1129
0.4640	0.6936	0.5928	0.2845	0.1420	0.0875	0.0469	0.0271
0.0103	0.0432	0.0540	0.1830	0.1563	0.1685	0.5218	1.1256
5.0449	5.6653	6.9651	1.2906	0.2762	0.2192	0.3199	0.3275

1.4476	3.7679	0.2198	0.2043	0.3201	0.3317	0.5996	8.7562
2.4252	0.1752	0.1746	0.2332	0.2499	0.1392	0.0568	3.2444
4.3669	0.2516	0.0513	0.0806	0.0217	0.0181	0.0071	0.0318
0.0052	0.1107	0.0563	0.0765	0.3566	0.6177	1.8708	6.7523
5.7235	6.8596	0.3147	0.1732	0.2816	0.2613	1.4554	0.3320
0.6424	0.3401	0.1532	0.2516	0.2734	0.6167	1.8782	1.0353
0.1639	0.1383	0.1284	0.1132	0.0358	0.0099	0.3715	0.2036
0.0473	0.0107	0.0161	0.0055	0.0042	0.0	0.0020	0.0686
0.0011	0.0390	0.0571	0.2361	0.5234	0.8064	0.8764	0.7700
0.3738	0.1090	0.0779	0.1134	0.1301	0.1936	0.0916	0.0987
0.0212	0.1555	0.0776	0.3045	0.2778	0.1763	0.0642	0.1402
0.0791	0.0633	0.0352	0.0215	0.0030	0.0843	0.0310	0.0206
0.0199	0.0032	0.0117	0.0029	0.0018	0.0543	0.0009	0.0299
0.0041	0.0381	0.1666	0.3354	0.3922	0.3672	0.2076	0.0915
0.0539	0.0544	0.0861	0.1091	0.0283	0.0557	0.0214	0.0149
0.0565	0.1927	0.0953	0.1367	0.0683	0.0205	0.0582	0.0295
0.0395	0.0021	0.0072	0.0	0.0537	0.0149	0.0043	0.0085
0.0122	0.0	0.0002	0.0	0.0	0.0	0.0	0.0032
0.0705	0.1714	0.2170	0.2268	0.1233	0.0999	0.0412	0.0273
0.0661	0.0821	0.0436	0.0390	0.0080	0.0116	0.0054	0.1307
0.0566	0.0952	0.0291	0.0317	0.0079	0.0072	0.0051	0.0216
0.0043	0.0	0.0	0.0067	0.0096	0.0022	0.0032	0.0067
0.0096	0.0	0.0	0.0	0.0	0.0	0.0128	0.0863
0.0773	0.1433	0.0406	0.0657	0.0112	0.0187	0.0246	0.0177
0.0275	0.0176	0.0064	0.0018	0.0019	0.0005	0.0224	0.0129
0.0115	0.0075	0.0029	0.0019	0.0010	0.0006	0.0029	0.0019
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CONCENTRATION FROM ELEVATED SOURCES
CONCENTRATIONS PATTERN

0.0	0.0	0.C	0.0031	0.0100	0.0215	0.1696	0.3102
0.4725	0.6021	0.1845	0.5370	0.7133	1.2434	0.3178	0.7915
0.4878	0.0962	0.0753	0.0698	0.0030	0.0073	0.0	0.0
0.0	0.0	0.C	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.C	0.0	0.0	0.0	0.0	0.0
0.0	0.0023	0.0068	0.0105	0.0231	0.0813	0.3843	0.7445
2.2865	1.0702	0.5971	1.1944	1.5989	1.5431	0.3616	0.2792
0.1681	0.2217	0.0334	0.0153	0.0	0.0	0.0	0.0006
0.0	0.0003	0.0	0.0030	0.0	0.0040	0.0	0.0052
0.0	0.0	0.0	0.0	0.0	0.0	0.0020	0.0005
0.0177	0.0058	0.0484	0.0773	0.3654	0.4432	1.6402	2.1362
1.1473	1.3740	2.7316	3.9241	1.0694	0.4153	0.1299	0.5359
0.0730	0.0238	0.0322	0.0044	0.0341	0.0005	0.0442	0.0051
0.0	0.0064	0.0050	0.0158	0.0	0.0087	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0012	0.0041	0.0484
0.0876	0.0973	0.7314	0.9683	1.0267	0.9822	1.7751	2.3630
2.0544	2.3618	1.4134	0.3298	0.2097	0.3315	0.1334	0.0536
0.0382	0.0437	0.0874	0.0013	0.0965	0.0017	0.0373	0.0138
0.0014	0.0225	0.0174	0.0180	0.0	0.0020	0.0	0.0
0.0	0.0	0.C	0.0	0.0174	0.0108	0.0807	0.1397
0.1978	0.4196	1.0225	0.7829	1.6712	2.7602	1.5439	4.2971
2.1886	0.6165	0.5639	0.1822	0.4422	0.0607	0.4461	0.0279
0.0871	0.1716	0.1956	0.0027	0.0097	0.0158	0.0272	0.0315
0.0355	0.0632	0.0087	0.0042	0.0	0.0	0.0	0.0
0.0	0.0	0.C	0.0293	0.0511	0.1776	0.3867	0.2124
0.3091	0.4409	0.6268	1.7816	0.9102	3.1866	2.9460	1.1067
0.4638	3.9829	0.7465	5.5037	0.7592	7.2025	0.0654	0.2465
0.4993	0.1711	0.1429	0.0114	0.0655	0.0931	0.0364	0.1494
0.0168	0.0034	0.0017	0.0010	0.0	0.0	0.0	0.0
0.0	0.0	0.0759	0.1413	0.2921	0.3281	0.2674	0.2596
0.7027	0.9241	1.2450	1.3639	1.8378	2.2826	0.7400	0.9391
5.1836	9.7833	1.6751	10.2400	0.3248	0.1819	0.3769	0.3168
0.5138	0.0758	0.0669	0.2050	0.0322	0.0684	0.0303	0.0109
0.0014	0.0007	0.0	0.0	0.0010	0.0	0.0006	0.0
0.0054	0.1376	0.4805	0.8884	0.3202	0.3368	0.5019	0.9790
1.3220	1.0031	2.8385	2.0901	0.8932	2.2353	1.4264	7.0755
13.7397	14.6947	0.4006	2.8504	0.7333	0.3244	1.0012	0.1292
0.0653	0.1230	0.0807	0.0543	0.0180	0.0061	0.0020	0.0067
0.0129	0.0027	0.0106	0.0212	0.0708	0.0284	0.0976	0.0458
0.6111	0.4662	0.2668	0.8496	1.1480	1.3874	1.3400	2.7757
2.4841	0.9094	0.7231	2.1104	2.4332	3.0543	6.8267	9.5712
4.9140	4.1791	0.5932	0.6112	0.9770	0.2599	0.2091	0.1029
0.0891	0.0809	0.0041	0.0118	0.0042	0.0026	0.0254	0.0115
0.0440	0.0195	0.1476	0.1855	0.2823	0.0976	0.3385	0.3147
0.2189	0.3452	1.7607	2.0335	0.8884	2.9216	3.5192	1.2061
1.6802	3.6928	4.4012	4.9384	5.7720	2.8738	1.3050	1.7836
2.0033	1.8023	1.7801	0.4306	0.3360	0.2753	0.5968	0.1404
0.5543	0.0132	0.7048	0.0043	0.0147	0.0408	0.5754	0.0314
0.[illegible]826	0.3291	2.7289	0.6127	3.6028	0.2775	0.1453	0.5374
0.8009	1.7629	3.4410	3.6368	0.6112	1.2788	1.7499	1.8334
1.6583	5.65[illegible]	6.7201	10.8785	1.5314	1.8786	1.6556	1.8005
1.2565	0.7016	0.5246	0.0689	0.9168	1.0818	1.0646	0.2474
1.0484	0.0073	0.0623	0.0165	0.5722	0.2721	1.3639	0.2825
3.6662	4.3452	9.6148	0.5844	11.0344	0.7693	0.6691	0.7555
1.3658	4.0083	4.6247	2.2017	1.5101	3.6567	1.7478	7.7709
2.2223	16.8049	9.5506	2.8509	1.6088	3.7495	3.3802	2.0376
1.0506	1.1399	1.9015	2.0418	1.0963	2.9956	1.7739	2.0207
0.4082	2.6744	0.2989	0.2618	1.9574	0.8479	2.7679	6.0050
11.2385	8.4333	16.3109	0.7481	0.8993	2.1198	0.8743	0.4954

2.4486	2.4219	1.3913	2.7142	1.9783	3.6278	2.4087	15.6369
1.7403	9.0529	3.6748	7.6117	3.0929	11.3643	2.5311	11.7663
3.2748	2.3151	3.9969	1.4870	3.9271	4.1711	0.9476	3.8767
0.5132	0.3475	1.3542	1.1551	4.1489	3.7892	8.0607	11.5522
21.9875	4.0856	5.5847	1.0920	1.3214	3.4375	1.9847	1.3300
1.8520	2.6326	3.6433	4.5506	2.9640	17.1818	1.6340	9.1487
1.9123	7.4002	13.0638	15.8487	2.4960	20.0409	5.1304	2.6083
6.1041	2.3340	1.6406	3.0440	5.3819	6.5413	1.0358	1.4649
1.1020	1.1002	4.3059	5.5031	6.7555	6.0680	12.8690	5.7214
5.4650	1.8976	0.1510	2.8827	2.8974	1.2817	1.0826	2.4631
4.8122	4.9959	5.2898	7.2913	3.3117	5.9312	1.3413	9.7158
5.3929	11.8206	20.4793	26.2729	5.3633	10.7915	8.8857	3.0656
4.8024	2.9488	4.6060	9.1045	4.4623	2.1032	2.4685	0.7626
4.7807	4.2577	7.4550	7.4193	14.5833	4.8030	5.5666	[illegible]02
2.4735	1.8309	0.3755	1.7720	1.0005	1.4500	3.0068	5.3934
7.0173	8.5057	2.8073	4.5413	5.2704	9.9117	5.8846	7.3295
7.9703	27.6221	11.5934	12.1285	12.4740	5.4295	5.8182	4.6059
4.6291	5.3523	6.7926	1.3663	1.8735	0.8572	1.3476	1.5368
5.1849	4.9180	23.4155	10.6890	7.8694	3.2331	6.6334	1.5550
0.1889	1.3817	0.8541	2.5430	2.4395	4.8440	5.8357	7.3964
3.3197	4.9628	3.5416	14.2490	10.3148	12.5358	7.8346	3.8759
6.1054	7.3009	6.0861	5.0598	3.2459	3.8363	5.0438	10.8308
6.8438	2.4348	1.7063	0.4824	0.5192	0.4158	2.3288	0.7870
17.7278	8.5687	8.3808	3.4400	4.3318	1.8696	2.1239	0.6683
1.5390	3.0395	3.1751	4.7849	4.8985	10.1357	2.9890	8.0620
2.8195	4.2199	2.3428	9.6127	11.4581	28.1810	7.0089	7.1915
12.5467	4.6257	3.0155	2.4977	2.9526	8.1201	6.6656	2.7510
1.5536	1.0526	0.6647	0.2955	0.2059	0.3265	11.2072	0.9114
11.4656	3.3175	5.2341	1.1583	2.8295	0.5688	1.1103	3.1358
2.8283	4.9414	9.6984	12.8346	7.8657	10.1919	2.9857	10.8767
2.5664	6.8202	2.0991	25.8024	17.3443	5.2528	8.3568	8.5301
1.9483	1.7482	1.9217	5.7415	2.9595	3.9711	1.9502	0.6823
0.3707	0.6763	0.0982	0.0769	4.5533	0.1642	4.2171	1.2611
3.2996	1.3777	1.9556	0.4300	1.6542	2.2646	1.8595	7.8545
10.6287	21.2391	6.3865	23.6142	3.3022	8.8112	4.5161	2.2313
1.3343	18.1744	1.0471	12.4067	7.7199	1.8636	3.7664	3.8543
0.9759	3.6551	1.9788	2.5170	0.4568	0.7676	0.2712	0.2537
0.1015	0.4286	0.0773	0.2695	0.6902	0.2555	1.2044	0.9557
1.7352	0.5324	0.6015	0.2926	1.1724	3.2261	12.8769	23.2456
4.0011	21.4995	2.2045	5.7289	0.9509	4.0867	1.3484	12.5975
1.5500	8.1383	2.7482	3.9544	3.6860	1.4813	1.9012	2.7168
0.9346	0.4205	1.2024	0.1431	0.1246	0.0453	0.1210	0.0091
0.0294	0.1181	0.4356	0.0255	0.6791	0.7941	1.0593	0.6697
0.7181	0.2520	0.3050	3.0410	4.1707	13.7485	17.4422	28.6084
1.6691	9.2896	0.7601	2.4653	0.7420	1.5959	2.3923	0.7893
0.4392	1.3730	4.3210	0.9822	1.6364	2.9606	0.9459	0.3253
0.9142	0.4159	0.1706	0.0418	0.1217	0.0076	0.0555	0.0351
0.0319	0.0132	0.0359	0.6580	0.2338	0.5180	0.2096	0.2568
0.1654	0.5453	2.4855	3.9628	3.4109	20.7188	10.6930	7.6525
0.5894	1.1541	1.5838	0.6995	1.2594	0.6179	0.4017	0.6021
2.3906	1.4932	1.3664	3.9628	0.9524	0.5591	0.7453	0.0689
0.3732	0.1036	0.0347	0.0002	0.0798	0.0166	0.0021	0.0157
0.0083	0.0270	0.1167	0.0063	0.1934	0.0935	0.1917	0.3606
1.3973	5.9063	0.9838	7.0929	2.5891	5.2604	3.0851	2.4722
0.3623	0.8378	0.4547	0.3488	0.1935	0.1792	0.9355	1.0225
0.6384	3.0792	1.4808	1.3302	0.8203	0.1013	0.2621	0.0041
0.0822	0.0	0.0213	0.0099	0.0552	0.0075	0.0	0.0103
0.0697	0.0027	0.0791	0.0026	0.1072	0.1413	0.9626	0.4205
6.2468	15.8861	1.1850	4.6200	1.4182	1.7225	0.0884	0.5453
0.1932	0.4252	0.2042	0.1321	0.7863	0.9087	0.4355	1.1932
1.3019	0.6975	0.6279	0.2632	0.0241	0.0316	0.0052	0.0001

0.0	0.0	0.0	0.0	0.0	0.0037	0.0	0.0031
0.0010	0.0003	0.0317	0.0006	0.2921	0.2575	0.1070	22.2653
11.9169	3.6954	1.0597	3.4259	0.0473	0.7694	0.1373	0.2156
0.1278	0.1199	0.5329	1.2421	0.3574	0.5584	0.2179	0.7920
0.5386	0.1964	0.0835	0.0899	0.0036	0.0028	0.0	0.0
0.0	0.0	0.0	0.0022	0.0	0.0015	0.0	0.0006
0.0	0.0001	0.1437	0.0072	0.1207	0.1025	0.1729	10.9410
3.1252	0.9988	0.0275	2.4527	0.0172	0.0046	0.0070	0.0572
0.1177	0.8331	0.3637	0.4159	0.0617	0.3230	0.1353	0.1979
0.0396	0.0289	0.0149	0.0478	0.0017	0.0002	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0863	0.0	0.0580	0.0311	0.0235	7.5113	0.0145	2.5682
0.0082	0.6787	0.0010	1.7747	0.0	0.0274	0.0	0.2544
0.2129	0.0705	0.0305	0.0778	0.0730	0.0270	0.0427	0.0210
0.0053	0.0018	0.0071	0.0028	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0186	0.0	0.0125	0.0227	0.0073	0.0021	0.0
0.0041	0.0	0.0	0.0	0.0	0.1244	0.0	0.1048
0.0405	0.0199	0.0329	0.0272	0.0235	0.0010	0.0082	0.0015
0.0027	0.0002	0.0043	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0044	0.0	0.0010	0.0
0.0024	0.0	0.0	0.0746	0.0	0.0502	0.0	0.0259
0.0	0.0083	0.0	0.0127	0.0	0.0003	0.0	0.0008
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CONCENTRATIONS FROM ALL SOURCES
CONCENTRATIONS PATTERN

0.0	0.0	0.0	0.0037	0.0127	0.0364	0.1958	0.3639
0.6038	1.0135	2.6000	7.3461	10.4849	2.8544	3.4892	5.8864
1.0486	0.3632	0.5017	5.1260	2.6537	0.1194	0.0259	0.0414
0.0188	0.0347	0.0451	0.0157	0.0393	0.0019	0.0058	0.0038
0.0115	0.0061	0.0182	0.0	0.0	0.0	0.0	0.0010
0.0010	0.0084	0.0113	0.0237	0.0461	0.1357	0.5028	0.8767
3.0574	3.1039	13.3257	15.0870	7.7682	3.2367	1.4402	0.8398
0.7501	0.8503	0.4429	0.3413	0.0578	0.0819	0.0179	0.0519
0.0815	0.0680	0.0770	0.0228	0.0695	0.0420	0.0797	0.0377
0.1038	0.0197	0.0356	0.0048	0.0583	0.0088	0.0123	0.0208
0.0461	0.0625	0.1078	0.1921	0.5160	0.7277	2.2696	3.4047
3.1223	7.4043	8.8854	14.6140	9.9701	1.2990	3.0219	6.0261
0.5218	0.3468	0.2562	0.1576	0.1610	0.0923	1.0035	0.2355
0.1405	0.0702	0.0881	0.0578	0.1203	0.0734	0.1188	0.0482
0.0570	0.0126	0.0926	0.0248	0.0401	0.0208	0.0640	0.1489
0.2041	0.3102	0.4796	1.4399	1.8990	2.2311	6.2910	4.8715
4.0634	4.5670	8.2679	5.9585	4.1569	1.1443	0.7748	0.6757
0.4536	0.4050	0.3282	0.1870	0.3400	1.0661	2.1150	0.1396
0.1076	0.1303	0.1605	0.2163	0.2215	0.0746	0.0786	0.1285
0.1600	0.1277	0.1058	0.1369	0.0583	0.0982	0.3344	0.4754
0.4995	0.8486	1.5223	1.3661	3.9603	11.9436	8.7808	6.3574
3.6841	1.8154	1.4314	0.9824	2.0849	1.0991	1.4011	2.4283
0.5811	0.5062	0.6471	0.3332	0.5469	0.2812	0.2265	0.2372
0.2317	0.8179	1.5897	0.1886	0.1093	0.2679	0.3228	0.2259
0.2307	0.1976	0.1078	0.1156	0.4715	1.8802	1.5068	0.7877
0.9281	1.1362	1.7197	3.0966	6.6079	11.3943	11.4652	2.3416
1.2984	4.8764	1.9718	15.1810	3.6205	10.5584	0.9941	0.9709
1.2840	0.8743	0.7376	0.5001	1.5839	1.1747	1.6698	1.2338
4.6158	1.4915	0.1354	0.2505	3.7434	0.5764	1.0233	0.9162
0.3859	0.0631	0.5198	3.8827	3.5226	1.9413	4.8920	2.9050
3.5552	3.1559	2.7681	7.5957	4.4279	6.6317	1.7304	2.7562
9.3070	14.5736	8.2314	12.3422	5.9559	1.4368	5.3554	6.0843
1.7258	0.4435	1.3305	2.1060	1.0487	0.3796	0.4432	0.3333
0.3244	0.2446	0.4861	0.4878	2.2620	1.7866	0.4904	0.3126
0.0779	0.7598	3.3586	6.5636	3.4145	5.1052	9.4715	3.8737
5.3427	2.2327	5.0815	8.1325	5.2108	3.3393	3.0286	13.8636
18.8399	22.7731	3.2781	8.1171	2.7660	4.6390	10.3988	2.4897
0.5574	0.7261	0.5738	0.5204	0.3708	0.2445	0.4744	0.3865
1.4944	2.6213	2.3918	6.8299	0.6788	0.2322	0.3499	0.2034
3.0000	3.2469	1.3294	1.8646	3.0912	3.2027	3.9277	3.9862
3.8375	9.8674	3.2435	3.0670	7.5938	6.1749	15.3004	14.7536
12.3568	8.9107	4.5099	6.5685	13.3248	4.3963	1.5649	1.3419
0.6943	0.7891	0.5150	0.4169	0.5701	2.8972	2.0560	0.5645
1.0119	0.9519	5.7748	0.6414	0.8506	0.5660	0.8080	0.9574
1.0449	2.1304	6.1507	3.1924	1.9558	4.0606	8.5706	3.6639
3.9630	5.4720	6.0592	19.8977	24.4317	25.5975	22.9878	12.0477
11.6779	13.5849	6.2105	5.5580	5.1842	2.9684	2.6667	1.2718
1.3865	0.8978	1.5855	0.6896	1.4637	0.7366	1.3214	0.7903
1.3729	1.0934	3.6194	2.2606	7.3760	0.6877	2.0769	1.6343
3.0195	5.3292	8.4302	4.8320	2.0783	7.8549	3.9171	3.3623
3.2265	7.9644	15.6831	30.9255	13.4413	25.6422	26.5931	26.1550
14.1075	6.0089	5.8807	6.8200	14.7910	3.6954	2.2682	3.0254
9.4233	1.4890	2.7701	0.7915	1.6789	1.5329	2.3017	1.8264
5.0086	6.6583	10.9438	1.4413	11.3903	8.0700	3.5637	1.6871
4.7564	13.5176	7.7794	9.0487	7.5798	12.3427	11.2697	9.9957
8.7755	30.8179	23.0555	12.4013	27.9504	32.4340	26.1762	24.8958
10.8670	18.8519	10.0933	24.1280	4.8508	4.5909	8.3612	7.0208
1.6746	4.7592	2.4793	1.7324	4.1750	4.8888	9.8521	11.7210
20.7661	9.8461	17.0087	1.1018	10.5972	5.6966	1.8925	3.7544

6.7911	7.5071	8.6208	4.8463	5.0637	6.5189	6.6148	19.6179
16.2743	20.6306	14.2018	23.5350	29.5845	33.1939	54.8149	40.8011
12.9236	17.4442	14.4609	9.0216	6.5696	9.7097	2.9540	5.5538
18.2121	11.8609	2.8443	2.4711	16.4675	13.5328	21.3769	19.4731
23.6503	4.7139	6.1420	2.6198	7.3185	5.9723	4.6140	2.7146
3.8034	5.3787	5.8394	9.9990	15.0832	20.8593	16.6864	34.8377
15.1321	45.9009	33.8254	50.1588	63.0899	86.7753	64.2655	15.1650
20.2677	7.5066	14.9529	7.6587	10.2311	9.1014	7.2390	8.6275
7.0344	3.0168	7.2201	11.0627	15.1576	21.8922	20.6979	6.8487
7.9209	2.5867	0.8261	3.6710	3.6745	4.7538	2.2356	4.0518
10.3544	14.1110	21.4180	14.3966	6.5481	17.0535	10.0524	23.1658
29.5219	45.3181	65.6960	73.4464	52.0417	50.2697	14.6463	9.7625
8.9854	13.9760	22.0015	12.7490	12.1850	9.0384	12.3752	5.1674
7.2587	5.6009	10.1255	18.7941	21.1379	7.8764	9.2032	9.6399
3.1360	2.3946	0.9582	2.7047	2.2613	3.3800	5.5595	23.5196
31.4821	22.2296	7.3640	12.4194	11.9862	18.3865	28.3973	30.4995
28.0327	54.8251	49.6629	39.1349	20.4072	9.1581	17.5597	26.6721
23.1136	21.1681	18.9056	6.2529	4.0080	7.1924	2.7787	2.6346
6.5410	6.7631	33.3246	13.1043	12.3188	12.2275	9.8810	1.9798
1.5213	2.3672	2.0750	8.3173	19.0205	8.1344	11.8866	26.4454
13.9170	16.3065	14.1163	32.3818	27.4157	39.7624	25.4227	17.8539
37.7991	44.9171	17.7711	8.3766	15.7915	8.9582	26.4719	33.9035
32.0226	8.4892	4.1477	2.1031	1.7863	5.5302	3.8471	2.0751
19.3418	10.0021	13.9349	9.0146	14.4899	3.3854	2.4863	8.6920
5.1672	9.0983	5.0824	14.8441	10.3982	13.1615	6.0277	10.7739
15.4248	12.9402	19.4608	27.5402	24.8874	46.4054	20.2544	32.6088
21.3384	9.9240	7.2684	5.0692	10.3000	31.1280	18.0142	19.8351
12.2998	11.8625	1.9700	1.0865	2.7123	2.5963	12.6038	1.7240
12.4066	4.9760	7.6249	2.1767	3.4893	0.9482	9.7489	7.2369
6.5249	6.9365	12.0336	24.9114	9.9156	12.0099	4.7963	16.3595
12.3890	18.7416	12.5293	34.4707	42.6040	15.9888	20.2521	15.3265
3.7189	3.5571	4.3130	9.2579	12.2906	14.1151	10.9176	4.9010
7.3733	1.7325	1.1037	4.0126	13.5131	1.0916	4.9561	2.0284
4.1668	6.3939	3.6973	4.0207	2.2282	3.1433	2.7505	11.3471
21.7016	24.8873	7.8483	28.6494	4.8728	10.2764	6.2713	4.6031
3.4462	20.3887	4.0902	15.6254	9.8733	3.8063	5.1773	5.2269
2.8629	5.9551	4.3147	4.5311	2.1850	2.2011	1.4122	1.4365
1.1570	4.8610	11.2925	5.2602	1.3017	0.8453	1.9540	2.3143
6.1099	1.6631	6.1283	0.5358	1.7008	3.9317	13.9923	26.1739
5.2367	24.3981	12.0931	8.1478	1.9884	5.3174	2.3916	13.6626
3.0740	9.8957	3.8298	5.1314	4.6605	2.8554	4.2456	4.9954
2.7959	1.9365	2.3143	0.9639	2.9630	1.7473	3.3669	2.1075
2.9823	1.9033	1.0484	0.7010	1.5191	1.4882	1.6886	1.6221
1.5640	0.6399	0.5631	3.4609	5.9736	14.7341	20.6455	34.1256
3.9300	14.8062	1.4542	3.0104	1.2388	2.1216	3.1053	1.4594
1.1829	2.1496	4.9235	4.3390	18.2022	16.9575	5.7996	1.9956
1.7558	1.2667	0.8025	3.6960	11.3158	5.0531	1.2053	1.6251
3.3218	0.6034	6.4410	4.2985	0.7437	1.3282	9.5399	0.8485
0.7317	0.8991	2.8714	5.4575	5.7511	21.5482	11.4108	8.3345
1.0332	1.3996	1.7937	0.9008	1.6765	0.7916	0.9214	1.0018
2.6198	2.1650	4.6373	17.1842	16.1042	7.0914	1.4834	0.4608
0.7627	0.4907	1.0525	2.3725	0.9429	0.4970	0.6024	3.7349
0.6642	4.5336	1.0904	0.5825	0.9520	0.6026	0.5359	6.0174
1.6922	6.2306	4.9506	8.9693	3.1677	5.5655	3.3287	2.5782
0.4115	0.8922	0.4988	0.3923	0.4138	3.7751	1.1237	1.3038
1.4657	4.8153	7.1539	7.1198	1.8986	0.5450	0.4785	0.1896
0.5367	1.1630	0.7840	0.4204	0.4308	0.3941	0.4410	1.2037
3.8007	1.2944	0.7277	0.3120	0.2952	0.5352	4.3663	0.5334
6.7108	16.5797	1.7778	4.9045	1.5602	1.8100	0.1353	0.5724
0.2035	0.4683	0.2582	0.3151	0.9426	1.0772	0.9572	2.3088
6.3468	6.3629	7.5931	1.5538	0.3003	0.2508	0.3251	0.3276

1.4476	3.7679	0.2198	0.2043	0.3201	0.3353	0.5996	8.7594
2.4263	0.1755	0.2063	0.2338	0.5420	0.3967	0.1637	25.9097
16.2838	3.9470	1.1109	3.5065	0.0689	0.7874	0.1444	0.2474
0.1330	0.2306	0.5892	1.3185	0.7140	1.1761	2.0887	7.5443
6.2622	7.0559	0.3981	0.2631	0.2852	0.2642	1.4554	0.3320
0.6424	0.3401	0.1532	0.2538	0.2734	0.6182	1.8782	1.0359
0.1639	0.1385	0.2721	0.1203	0.1565	0.1123	0.5443	11.1446
3.1725	1.0095	0.0436	2.4583	0.0214	0.0046	0.0090	0.1258
0.1188	0.8721	0.4208	0.6520	0.5851	1.1295	1.0117	0.9679
0.4134	0.1379	0.0928	0.1612	0.1318	0.1939	0.0916	0.0987
0.0212	0.1555	0.0776	0.3045	0.2778	0.1763	0.0642	0.1402
0.1654	0.0633	0.0932	0.0526	0.0265	7.5956	0.0455	2.5889
0.0282	0.6819	0.0127	1.7776	0.0018	0.0817	0.0009	0.2843
0.2170	0.1085	0.1971	0.4133	0.4652	0.3942	0.2503	0.1124
0.0592	0.0561	0.0932	0.1119	0.0283	0.0557	0.0214	0.0149
0.0565	0.1927	0.0953	0.1367	0.0683	0.0205	0.0582	0.0295
0.0395	0.0207	0.0072	0.0125	0.0764	0.0222	0.0063	0.0085
0.0162	0.0	0.0002	0.0	0.0	0.1244	0.0	0.1080
0.1109	0.1913	0.2499	0.2541	0.1468	0.1009	0.0493	0.0288
0.0689	0.0822	0.0479	0.0390	0.0080	0.0116	0.0054	0.1307
0.0566	0.0952	0.0291	0.0317	0.0079	0.0072	0.0051	0.0216
0.0043	0.0	0.0	0.0067	0.0140	0.0022	0.0042	0.0067
0.0120	0.0	0.0	0.0746	0.0	0.0502	0.0128	0.1122
0.0773	0.1516	0.0406	0.0784	0.0112	0.0190	0.0246	0.0186
0.0275	0.0176	0.0064	0.0018	0.0019	0.0005	0.0224	0.0129
0.0115	0.0075	0.0029	0.0019	0.0010	0.0006	0.0029	0.0019
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

RATIO OF CONCENTRATION DUE TO AREA SOURCES TO TOTALC ONCENTRATION

0.0	0.0	0.C	C.1519	C.2140	0.4091	0.1339	0.1475
0.2175	0.4059	0.9290	C.9269	C.9320	0.5644	0.9089	0.8655
0.5348	0.7352	0.8499	0.9864	C.9989	0.9390	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	C.0	0.0	0.0	0.0	1.0000
1.0000	0.7252	0.3962	C.5576	C.4995	0.4010	0.2358	0.2378
0.2522	0.6552	0.9559	C.9208	0.7942	0.5233	0.7489	0.6676
C.7759	0.7393	0.9245	C.9552	1.0000	1.0000	1.0000	0.9894
1.0000	0.9950	1.0000	C.8676	1.0000	C.9039	1.0000	0.8611
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.8360	0.9761
0.6161	0.9071	0.5514	0.5978	0.2918	0.3910	0.2773	0.3726
0.6325	0.8144	0.6926	C.7315	0.8927	0.6803	0.9570	0.9111
C.8600	0.9313	0.8744	C.9722	C.7885	0.9949	0.9560	0.9782
1.0000	0.9092	0.9429	C.8383	1.0000	0.8808	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	0.9442	0.9363	0.6750
C.5709	0.6864	0.5176	C.3275	C.4594	0.5597	0.7178	0.4468
0.4944	0.4829	0.8290	C.9447	0.9496	0.7103	0.8279	0.9207
C.9158	0.8920	0.7335	C.9931	C.7161	0.9984	0.9824	0.9013
0.9865	0.8272	0.8917	C.9168	1.0000	0.9729	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	0.7023	0.8895	0.7586	0.7060
0.6040	0.5056	0.3283	C.4269	0.5780	0.7689	0.8242	0.3241
0.4059	0.6604	0.6060	C.8145	C.7879	0.9448	0.6816	0.9885
0.8502	0.6610	0.6978	C.9920	0.8726	0.9438	0.9797	0.8670
0.8470	0.9227	0.9945	C.9775	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	C.7466	0.8915	0.9055	0.7434	0.7303
0.6669	0.6120	0.6355	C.4247	0.8623	0.7203	0.7431	0.5274
0.6428	0.1832	0.6214	C.6375	0.7903	0.3178	0.9342	0.7461
0.6111	0.8043	0.8063	C.9772	C.9586	0.9208	0.9792	0.8789
C.9964	0.9977	C.9876	C.996C	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	0.8540	C.9636	0.9171	0.8310	0.9453	0.9106
0.8023	0.7072	0.5502	0.8204	0.5850	0.6558	0.5724	0.6593
0.4430	0.3287	0.7965	C.1703	C.9455	0.8734	0.9296	0.9479
0.7023	0.8291	0.9497	C.9026	C.9693	0.8199	0.9315	0.9672
0.9955	0.9971	1.0000	1.0000	C.9996	1.0000	0.9988	1.0000
C.9302	0.8189	0.8569	C.8646	0.9062	0.9340	0.9470	0.7473
C.7526	0.5507	0.4414	0.7430	0.8286	0.3306	0.5290	0.4896
C.2707	0.3547	0.8778	C.6488	C.7349	0.9301	0.9037	0.9481
0.8828	0.8307	0.8593	C.8956	C.9515	C.9749	0.9958	0.9827
0.9913	0.9990	0.9956	C.9969	0.8956	0.8778	0.7210	0.7750
0.7963	0.8564	0.7993	0.5444	C.6286	0.5668	0.6588	0.3037
0.3527	0.9078	0.7771	C.3119	0.6796	0.5054	0.5538	0.3513
C.6C36	0.5310	0.8792	C.9123	C.9267	0.9409	0.8664	0.9233
C.8717	0.8975	0.9921	C.9718	0.9926	0.9991	0.9876	0.9797
C.9565	0.9795	0.9744	C.7108	0.6681	0.8275	0.5810	0.6713
C.7905	0.8379	0.7137	C.3630	0.5458	0.2805	0.5894	0.6708
0.5760	0.3251	0.2736	C.7518	0.7637	0.8877	0.9432	0.8520
0.8285	0.8673	0.7134	C.9225	0.9352	0.9073	0.7762	0.8896
C.6C02	0.9853	0.5555	C.9938	C.9900	0.9446	0.5646	0.9603
0.6485	0.6990	0.2460	0.729C	0.5116	0.5965	0.9300	0.6711
0.7348	0.6692	0.5918	C.2473	C.7059	0.8372	0.5533	0.4547
C.4860	0.2896	0.5715	0.6482	0.8861	0.9267	0.9377	0.9312
0.9109	0.8832	0.9108	0.9019	0.9380	0.7072	0.5306	0.9182
C.8887	0.9951	0.9775	C.9791	0.6592	0.8225	0.4074	0.8453
C.268C	0.3474	0.1214	C.5945	0.0312	C.9047	0.8123	0.5522
0.7128	0.7035	0.4055	0.7567	C.8008	0.7037	0.8449	0.2229
0.7468	0.4547	0.5858	C.7669	C.9424	0.8844	0.8709	0.9182
C.9033	0.9395	0.8114	C.9154	0.7740	0.3475	0.7878	0.7122
C.7562	0.4381	0.8794	C.8489	C.5312	0.8266	0.7191	0.4877
0.4588	0.1435	0.C410	C.321C	0.9151	0.6279	0.5380	0.8681
0.6394	0.6774	0.8386	C.4399	0.6093	0.4435	0.6359	0.2029

0.8931	0.5612	0.7412	0.6766	0.8955	0.6576	0.9538	0.7116
0.7466	0.8673	0.7236	0.8352	0.4022	0.5704	0.6792	0.3070
0.9718	0.9707	0.5239	0.5325	0.7481	0.7200	0.6229	0.4068
0.0703	0.1333	0.0907	0.5832	0.8194	0.4244	0.5698	0.5101
0.5131	0.5106	0.3761	0.5449	0.8035	0.1763	0.9021	0.7374
0.8736	0.8388	0.6138	0.6840	0.9604	0.7690	0.9202	0.8280
0.6988	0.6891	0.8903	0.6025	0.4740	0.2813	0.8569	0.8302
0.8433	0.6353	0.4036	0.5026	0.5543	0.7228	0.3782	0.1646
0.3100	0.2664	0.8172	0.2147	0.2115	0.7304	0.5157	0.3921
0.5353	0.6460	0.7530	0.4935	0.4943	0.6522	0.8666	0.5806
0.8173	0.7392	0.6883	0.6423	0.8969	0.7853	0.3933	0.6360
0.4655	0.7890	0.7907	0.2859	0.6338	0.7673	0.8005	0.8524
0.3414	0.2398	0.2637	0.6052	0.3101	0.3902	0.3951	0.6711
0.2113	0.2354	0.6082	0.3448	0.5576	0.5710	0.4592	0.7707
0.7771	0.6174	0.6188	0.6343	0.5603	0.4609	0.7928	0.7597
0.7157	0.4962	0.7666	0.6901	0.3887	0.4071	0.6687	0.8273
0.7997	0.7472	0.6407	0.7815	0.5326	0.8808	0.5150	0.4167
0.2073	0.2728	0.2974	0.1843	0.3612	0.7356	0.3287	0.2146
0.8759	0.4163	0.5884	0.6943	0.8717	0.4045	0.5091	0.7203
0.7615	0.6957	0.7491	0.5600	0.6238	0.6847	0.6918	0.7829
0.8385	0.8375	0.6575	0.3960	0.7945	0.5718	0.8095	0.6805
0.7863	0.7132	0.5886	0.7706	0.7093	0.9248	0.3947	0.6208
0.0834	0.1433	0.3986	0.6184	0.7010	0.4477	0.1458	0.9231
0.7022	0.6659	0.3753	0.6777	0.5289	0.2299	0.5041	0.2517
0.8172	0.6739	0.8796	0.6510	0.5396	0.3927	0.6540	0.7795
0.4120	0.5339	0.5851	0.5073	0.7133	0.7391	0.6300	0.8613
0.8737	0.9113	0.6626	0.7280	0.9241	0.8743	0.1108	0.4714
0.0758	0.3333	0.3136	0.4678	0.1891	0.4002	0.8861	0.5667
0.5665	0.2876	0.1941	0.4848	0.2067	0.1514	0.3775	0.3351
0.7929	0.6361	0.8325	0.2515	0.5929	0.6715	0.5874	0.4434
0.4761	0.5085	0.5544	0.3798	0.7592	0.7187	0.8214	0.8608
0.9497	0.6096	0.9110	0.9808	0.6630	0.8496	0.1491	0.3782
0.2081	0.7845	0.4711	0.8931	0.2576	0.2796	0.3239	0.3078
0.5102	0.1466	0.1863	0.1758	0.3223	0.1426	0.2799	0.5153
0.6128	0.1086	0.7440	0.2060	0.2181	0.5104	0.2725	0.2626
0.6591	0.3862	0.5414	0.4445	0.7910	0.6513	0.8080	0.8234
0.9123	0.9118	0.9932	0.9488	0.4698	0.6977	0.3837	0.5870
0.7160	0.6799	0.9018	0.4538	0.3106	0.1795	0.0797	0.1119
0.2359	0.1188	0.8177	0.2969	0.5218	0.2314	0.4362	0.0780
0.4958	0.1776	0.2824	0.2294	0.2091	0.4812	0.5522	0.4561
0.6657	0.7828	0.4804	0.8515	0.9579	0.9741	0.9641	0.9957
0.9901	0.9380	0.5846	0.9636	0.5530	0.4664	0.3727	0.5871
0.5408	0.6061	0.4583	0.1213	0.3018	0.0669	0.1552	0.1617
0.5753	0.4401	0.4773	0.1811	0.4010	0.2478	0.2296	0.4591
0.6287	0.3613	0.1224	0.7736	0.9101	0.8254	0.8369	0.8370
0.4793	0.6717	0.7874	0.9887	0.9892	0.9985	0.9539	0.9784
0.9904	0.9781	0.9944	0.8469	0.6857	0.6100	0.9780	0.6974
0.7740	0.3935	0.1344	0.2739	0.4069	0.0385	0.0629	0.0818
0.4295	0.1754	0.1170	0.2234	0.2488	0.2194	0.5640	0.3990
0.1522	0.3103	0.7053	0.7694	0.9409	0.9212	0.4975	0.8505
0.5106	0.7889	0.9670	0.9999	0.9153	0.9667	0.9965	0.9958
0.9875	0.9940	0.8930	0.9891	0.7968	0.8449	0.6422	0.9401
0.1743	0.0521	0.8013	0.2092	0.1827	0.0548	0.0732	0.0411
0.1196	0.0611	0.0883	0.1110	0.5325	0.9525	0.1675	0.2158
0.5644	0.3605	0.7930	0.8132	0.5680	0.8141	0.4523	0.9782
0.8468	1.0000	0.9728	0.9764	0.8719	0.9810	1.0000	0.9914
0.9817	0.9979	0.8914	0.9916	0.6369	0.7361	0.7796	0.2117
0.0691	0.0418	0.3335	0.0580	0.0910	0.0483	0.3467	0.0473
0.0508	0.0922	0.2091	0.5809	0.1658	0.1565	0.5451	0.4875
0.7949	0.8904	0.9173	0.8306	0.9198	0.8742	0.9841	0.9997
1.0000	1.0000	1.0000	1.0000	1.0000	0.9890	1.0000	0.9996

0.9996	0.9984	0.8465	0.9576	0.4610	0.3509	0.3467	0.1272
0.2682	0.0637	0.0461	0.0230	0.3142	0.0229	0.0492	0.1285
0.0392	0.4799	0.0955	0.0580	0.4994	0.5252	0.8957	0.8950
0.9140	0.9722	0.7903	0.6582	0.9873	0.9893	1.0000	1.0000
1.0000	1.0000	1.0000	0.9913	1.0000	0.9976	1.0000	0.9994
1.0000	0.9990	0.4720	0.9404	0.2285	0.0878	0.6824	0.0183
0.0149	0.0106	0.3696	0.0023	0.1973	0.0	0.2240	0.5453
0.0093	0.0447	0.1357	0.3621	0.8946	0.7140	0.8662	0.7956
0.9042	0.7906	0.8396	0.7036	0.9868	0.9989	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.4782	1.0000	0.3775	0.4092	0.1141	0.0111	0.6805	0.0080
0.7080	0.0047	0.9216	0.0016	1.0000	0.6649	1.0000	0.1051
0.0188	0.3507	0.8453	0.8117	0.8431	0.9315	0.8295	0.9135
0.9106	0.9687	0.9237	0.9749	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	0.1003	1.0000	0.0	0.7029	0.6714	0.6743	1.0000
0.7498	0.0	1.0000	0.0	0.0	0.0	0.0	0.0296
0.6353	0.8961	0.8683	0.8928	0.8400	0.9900	0.8346	0.9495
0.9603	0.9980	0.9109	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	0.0	0.0	1.0000	0.6840	1.0000	0.7622	1.0000
0.7966	0.0	0.0	0.0	0.0	0.0	1.0000	0.7693
1.0000	0.9454	1.0000	0.8380	1.0000	0.9822	1.0000	0.9554
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

OSSERVATORIO METEOROLOGICO DI BRERA
20121 MILANO - VIA BRERA, 28
DIREZIONE TEL. 80.04.30 - UFFICI E LABOR. TEL. 80.14.13

	Receptor Points (°)		Concentrations in $\mu g\ m^{-3}$		
	x	y	Point Sources	Area Sources	Total
1	347329	555153	12.5	27.1	39.6
2	347926	555145	10.7	39.4	50.1
3	347576	555038	11.8	33.4	45.2
4	347700	555200	6.3	16.8	23.1
5	347000	555700	3.2	3.6	6.8
6	348500	555200	5.3	14.7	20.0

(°) GAUSS-KRUGER Coordinates

Encl. lett. 5th July, 1977

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Sivertsen; Norway (KILDER)

NILU
TEKNISK NOTAT NR 1/77
DATO: JANUAR 1977

APPLICATION OF THE NORWEGIAN MULTIPLE SOURCE MODEL "KILDER" TO THE NATO/CCMS DATA BASE FROM THE FRANKFURT AREA

BY
BJARNE SIVERTSEN

PREPARED AS A PRACTICAL DEMONSTRATION OF URBAN AIR QUALITY SIMULATION MODELS FOR THE NATO/CCMS AIR POLLUTION PILOT STUDY, MODELING PANEL, TECHN. DOC. M.P. 1/1977, I.S.N.

NORWEGIAN INSTITUTE FOR AIR RESEARCH
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SUMMARY

The multiple source Gaussian type dispersion model "KILDER" has been applied to the standard data base submitted by the Federal Republic of Germany as part of the practical demonstration of urban air quality simulation models in the NATO/CCMS air pollution pilot study.

Spatial distributions of the annual average ground level concentration of SO_2 has been calculated and presented as isopleth maps. Contributions from point sources and area sources have been presented separately. Annual mean concentrations at 6 specified receptor points, and the cumulative frequency distribution for one of these points are also presented.

The sensitivity of varying the resolution of the input meteorology is briefly discussed, and demonstrated to be of great importance in the results.

1 INTRODUCTION

The Norwegian Institute for Air Research has been asked to exercise the gaussian type dispersion model "KILDER" (1) as a part of the practical demonstration of urban air quality simulation models in the NATO/CCMS air pollution pilot study. The model is described in the NATO/CCMS document M.P. 1/1975 I.I.G.

The data base consisted of:

- average SO_2 emissions for area and point sources in the Frankfurt area
- joint frequency distribution of wind and stability data from one meteorological station for the period August 1971 to July 1972
- hourly values of meteorological data for every 6 hour given on magnetic tape for the period August 1971 to July 1972

The results should include:

- annual average concentrations for the whole test area (with mesh size 1km x 1km)
- annual mean values and cumulative frequency distributions for 6 specified receptor points.

Meteorological data from the magnetic tape have been used for this practical demonstration. The data have been adapted to the model, in order to avoid alterations in the model itself.

2 SHORT DESCRIPTION OF THE MODEL

The model "KILDER" calculates short term or long term ground level concentrations from point and area sources. Area sources are treated as virtual point sources, with specification of width and height (sylindrical) and dispersion parameters (stability) as input. Plume rise is calculated for point sources by Holland's formula for small sources, Stümke's formula for medium sized heat emissions, and Briggs' formulaes for large sources and for stable atmospheric conditions (2).

2.1 Basic equations

In the following brief presentation of the model, the notation usually found in the litterature have been used, and is therefore not explained for all variables.

Point sources (continous emission)

The concentration in one point due to emissions from one source is given by:

$$\chi = \frac{Q \cdot E}{2\pi\sigma_y\sigma_z u} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)$$

where

$$E = \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \alpha \cdot \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]$$

For long time average concentrations sector-averaging is used:

$$\chi = \sum_{us} \frac{Q \cdot N \cdot E \cdot f}{(2\pi)^{3/2}\sigma_z \cdot l \cdot u}, \quad \sigma_y = Ax^p, \quad \sigma_z = Bx^r$$

where.

f = frequency of wind speed class (u) and stability class (s)

$l = (x^2+y^2)^{1/2}$

N = number of sectors for given meteorological data

α = reflection factor

Area sources

The area sources are treated as virtual point sources with dispersion parameters

$$\sigma_y = A \cdot (x+x_y)^p$$

$$\sigma_z = B \cdot (x+x_z)^r$$

where

$$x_y = \left(\frac{b}{4.3A}\right)^{1/p} \qquad x_z = \left(\frac{h}{4.3B}\right)^{1/r}$$

b = width of area
h = height of area

2.2 Plume rise formulaes

$$Q_H = \text{heat emission} \left[\text{cal/s}\right]$$

Unstable and neutral air: $Q_H < 2\cdot10^5$: $\Delta h = \frac{1}{u}\left[1.5\cdot d\cdot v_g + 4\cdot10^{-5}\, Q_H\right]$

$2\cdot10^5 < Q_H < 7\cdot10^6$: $\Delta h = \frac{1}{u}\left[1.5\cdot d\cdot v_g + 65\cdot d^{3/2}\left(\frac{T_s-T}{T_s}\right)^{1/2}\right]$

$Q_H > 7\cdot10^6$: $\Delta h = \frac{F^{1/3}}{u}\,(10h_s)^{2/3}$

Stable air: $\Delta h = 2.9\left(\frac{F}{u\cdot s}\right)^{1/3}$

where $s = \frac{g}{T}\frac{\partial\theta}{\partial z}$

$$F = g\cdot v_g (d/2)^2\, \Delta T/T_s$$

2.3 Meteorological parameters

Stability classification

The meteorological data have been devided into 4 stability classes corresponding to: unstable (Klug IV and V), neutral (Klug III), stable (Klug II) and stable (Klug I).

Diffusion parameters

In the version used for this practical demonstration a modified version of Singer and Smith's values from Brookhaven have been used (3). The dispersion parameters are given on the form:

$$\sigma_z = Bx^r$$

The parameters B and r are specified for 4 stability classes. The following values of parameters have been used:

Stability class	B	r
unstable	0.33	0.86
neutral	0.26	0.78
stable	0.16	0.74
very stable	0.06	0.71

The original one hour average meteorological data from magnetic tape have been used to calculate the joint frequency of the stability, wind speed and wind direction.

Horizontal wind field

For calculating long time average concentrations the wind frequency distributions are given for 30-degree-sectors. The data are also devided into 4 classes of wind speed: 0-2, 2-4, 4-6 and >6 m/s. The frequency of calm (4.8%) has been included in the lowest wind speed class.

When calculating the one hour average concentrations (as basis for the cumulative frequency distributions) the wind direction is given with an acuracy of one degree, and the measured wind speed is given for each 0.1 m/s. The wind is in these calculations assumed to be constant with height.

3 APPLICATION OF THE DATA BASE PROVIDED

In this practical demonstration the data base and the test area have been adapted to the existing model "KILDER". Modifications of the data base have been included to utilize them with as little changes in the model as possible. These modifications includes converting area source emissions to the 1 km x 1 km-grid, and rearranging the frequency distribution of meteorological data.

It should be mentioned, however, that an alternative would be to modify the model to fit the data and the test area.

3.1 The test area

The model in its present form is limited to a grid of 28 x 24 points. The required mesh-size of 1 km x 1 km implies that the total area covered is 28 x 24 km. The area chosen for the calculations are in Gauss-Krüger-coordinates:

longitude 1200 - 4000, latitude 2000 - 4400.

3.2 The emission inventory

Within the specified area all point sources with an annual average SO_2-emission of more than 10 kg/h is included. Also all area sources with SO_2-emissions of more than 25 kg SO_2/h during the heating period were included in the program.

This adds up to a total of 148 point and area sources, representing about 90% of the total emissions in the specified test area. The remaining 10% are mostly small area sources in the outer part of the test area.

The maximum SO_2-emissions (Q_A) of the area sources are given at a temperature of -12°C. An average number of 1560 heating hours per year is given. The annual average SO_2-emission per hour (Q_h) is thus calculated from:

$$Q_h = Q_A \times 1560/(365 \times 24).$$

The average source height in each square kilometer of the area is calculated from the standard data base, and used as input to the model.

3.3 Meteorological data

The one hour average meteorological data from magnetic tape have been used to calculate the joint frequency distributions of wind and stability. The calculated frequency distribution is given in table 1 for the period 1.8.71 - 31.7.72.

Table 1: Annual joint frequency distribution of wind and stability.

FREKVENSFORDELING SOM FUNKSJON AV VINDRETNINGEN (ENHETSPROSENT)

VI HAR BENYTTET KLUGS METODE FOR BEREGNING AV STABILITETSKLASSER

DATA FRA

FRANKFURT A.M. FOR PERIOD 1/8-71-31/7-72

WIND DIRECTION	UNDER 2.0 M/S				2.0- 4.0 M/S				4.0- 6.0 M/S				OVER 6.0 M/S				
STABILITY	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	ROSE
30	.9	.6	1.0	1.1	1.3	2.6	1.1	.7	.1	4.2	0.0	0.0	0.0	3.7	0.0	0.0	17.8
60	.7	.4	1.4	3.7	1.0	3.5	2.2	1.3	.1	1.0	0.0	0.0	0.0	.4	0.0	0.0	16.4
90	.7	.6	.7	1.4	1.0	1.5	.3	.3	.1	.6	0.0	0.0	0.0	.0	0.0	0.0	7.3
120	.4	.4	.7	.6	.3	.4	.1	.0	.0	.1	0.0	0.0	0.0	0.0	0.0	0.0	3.2
150	.1	.3	.4	.1	.2	.1	.0	.1	.0	.1	0.0	0.0	0.0	0.0	0.0	0.0	1.7
180	.7	.5	.8	1.0	.2	2.0	.8	.2	.0	.6	0.0	0.0	0.0	.2	0.0	0.0	7.1
210	.6	.4	.8	1.3	1.1	4.8	1.4	.6	.1	5.4	0.0	0.0	0.0	2.2	0.0	0.0	19.7
240	.3	.7	.5	.4	.8	2.6	1.0	.1	.0	2.3	0.0	0.0	0.0	4.5	0.0	0.0	12.5
270	.2	.2	.1	.2	.3	1.0	.2	.1	.0	1.4	0.0	0.0	0.0	1.4	0.0	0.0	5.1
300	.1	.1	.2	.1	.1	.0	.1	.0	0.0	.1	0.0	0.0	0.0	.2	0.0	0.0	2.4
330	.0	.2	.1	.1	.3	.9	.1	.1	.1	.6	0.0	0.0	0.0	.1	0.0	0.0	3.7
360	.7	.3	.4	.4	.2	.8	.3	.1	0.0	.6	0.0	0.0	0.0	.7	0.0	0.0	3.5
TOTAL	4.8	4.7	7.2	11.1	7.4	21.1	8.3	3.8	.8	18.6	0.0	0.0	0.0	12.5	0.0	0.0	100.0

ANTALL OBSERVASJONER: 2719

Three set of calculations have been carried out:

1. For mapping the spatial concentration distribution based on calculations in 672 grid points, the meteorological data have been divided into 48 classes ; 12 wind directions and 4 wind speed classes. Neutral atmospheric stratification has been assumed as an annual average in these cases. This has been done to save computertime.

2. When calculating the annual average concentrations at specified grid points, the meteorological data have been divided into 192 classes: 12 wind directions, 4 wind speed classes and 4 stability classes as shown in table 1. This difference in the resolution of the meteorological data have produced somewhat different results in the isopleth maps and in table 2, for the specified receptor points.

3. The frequency distribution of meteorological data (192 classes) have been used together with the annual average emission rates as a bases for calculating cumulative frequency distributions of SO_2-concentrations. The emission data have not been broken up into hourly emission rates. The frequency distribution for one receptor point is however, presented to show an example of the model output.

4 RESULTS OF THE MODEL CALCULATIONS

4.1 Spatial distributions

The calculated annual average concentration distribution of SO_2 is presented in the figures 1, 2 and 3 for emissions from point sources, area sources and both groups combined.

4.2 Mean concentrations at specified points

The annual average concentrations at 6 specified receptor points are presented in table 2.

Table 2: Annual average SO_2-concentration ($\mu g/m^3$) at 6 specified receptor points.

	Receptor point		Annual aver. conc. ($\mu g/m^3$)		
	x-coord.	y-coord.	Point sources	Area Sources	All
1	22.29	26.53	15.3	110.5	125.8
2	28.25	28.15	16.9	86.4	103.3
3	24.76	28.98	19.1	108.1	127.2
4	16.00	27.00	21.5	56.2	77.7
5	19.00	32.00	20.8	32.6	53.4
6	34.00	27.00	7.7	40.5	48.2

4.3 Cumulative frequency distribution at one point

The cumulative frequency distribution of SO_2-concentration from point and area sources on an annual basis is presented for receptor point no. 1 in figure 4. This distribution does not include hourly variation in the emissions of SO_2. It is therefore different from the case where the emission rates have been broken up for instance as a function of air temperature. The procedure for this have, however, not been specified.

4.4 Discussion of the results

As can be seen from the presentation of the results, there is a difference between the concentrations given on the isopleth maps and those presented in table 2. This can be explained by the difference in the resolution of the input meteorological data. The area sources produce a much higher concentration in the cases with stable air and wind less than

2 m/s (which occur 11% of the time) than the concentration, produced during neutral atmospheric conditions. (Only the latter stability category is used for producing the maps).

The results thus demonstrate how sensitive the calculations of groundlevel concentrations are to the input meteorology. It is questionable how realistic the cases with stable atmospheric conditions is over the city of Frankfurt. There are reasons to assume that these cases under estimate the vertical spread, and thus over estimate the concentrations. By changing the average building height (and thus the initial spread of area sources) the resulting concentrations would be between those presented in the maps and those shown in table 2. This alteration and "calibration" of the model have however not been carried out.

REFERENCES

(1) Schjoldager, J. PROGRAM KILDER, Beregning av spredning fra punktkilder og volumkilder. NILU Teknisk Notat nr. 2/75 Norw. Inst. for Air Research, Nov. 1974.

(2) Sivertsen, B. Plume Rise Calculations NILU Teknisk Notat nr. 80/74 Norw. Inst. for Air Research, July 1974.

(3) Smith, M. Recommended Guide for the Prediction of the Dispersion of Airborne Effluents ASME, New York 1968.

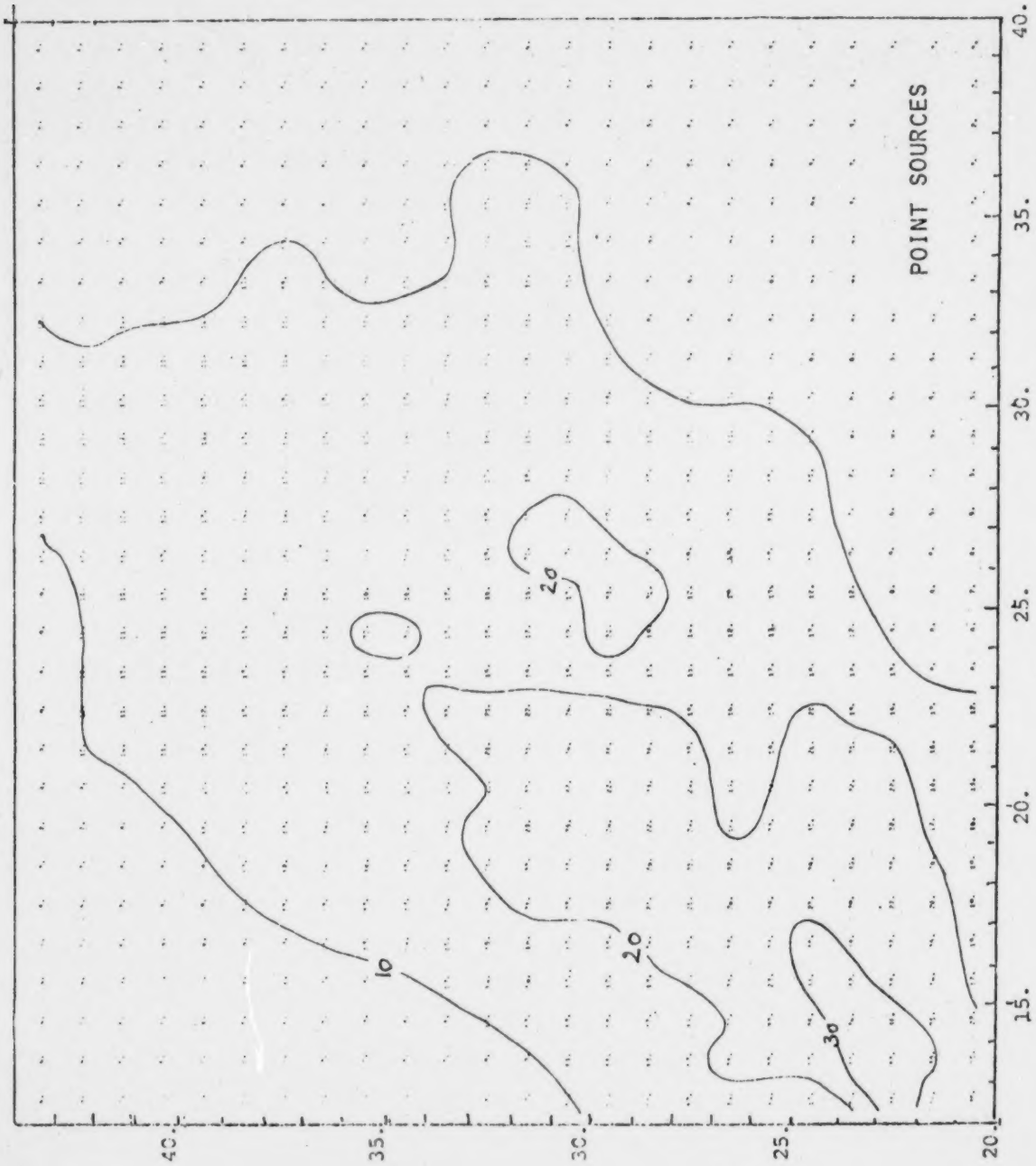

Figure 1: Annual average concentration of SO_2 ($\mu g/m^3$) due to emissions from point sources.

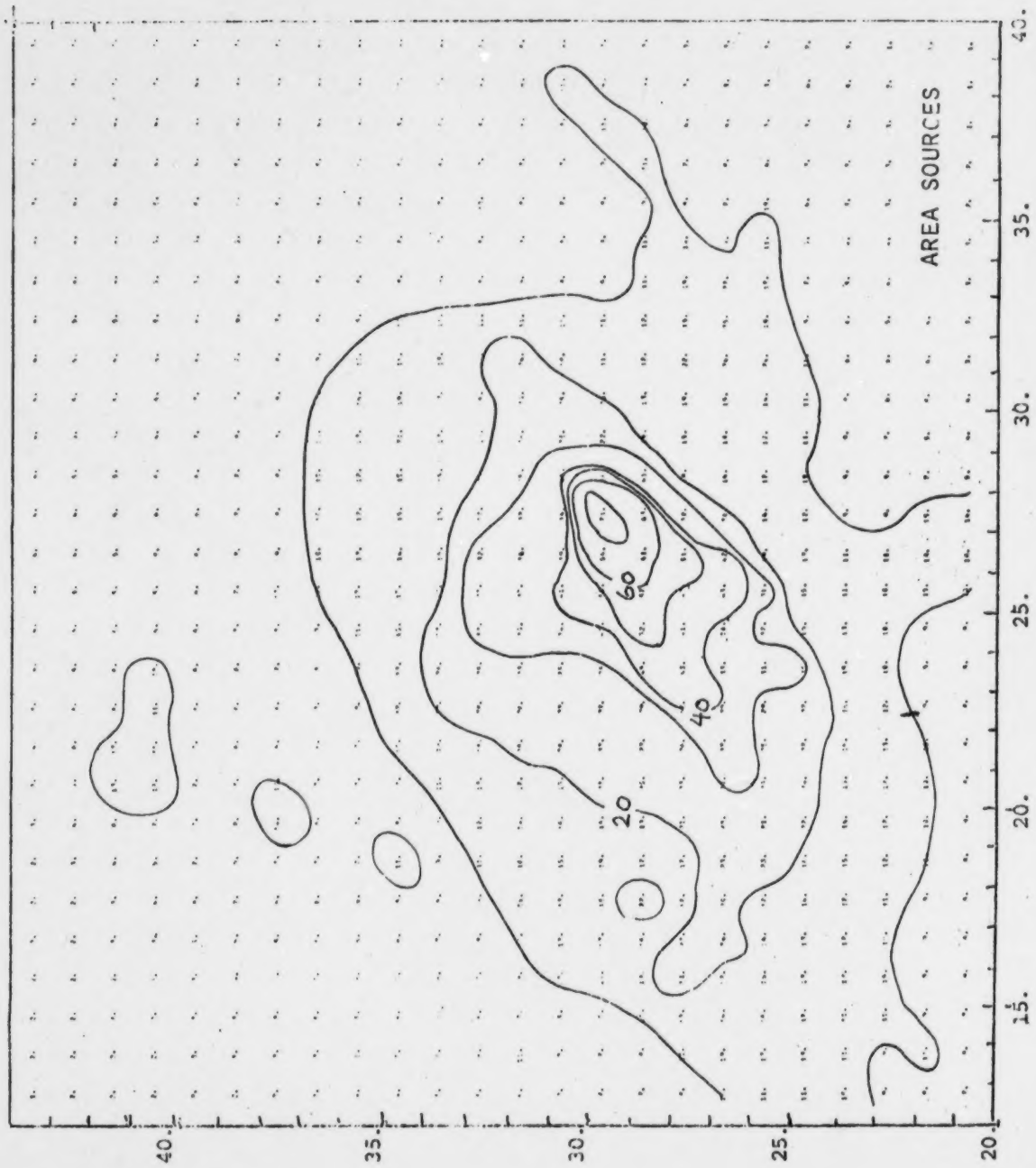

Figure 2: Annual average concentration of SO_2 ($\mu g/m^3$) due to emissions from area sources.

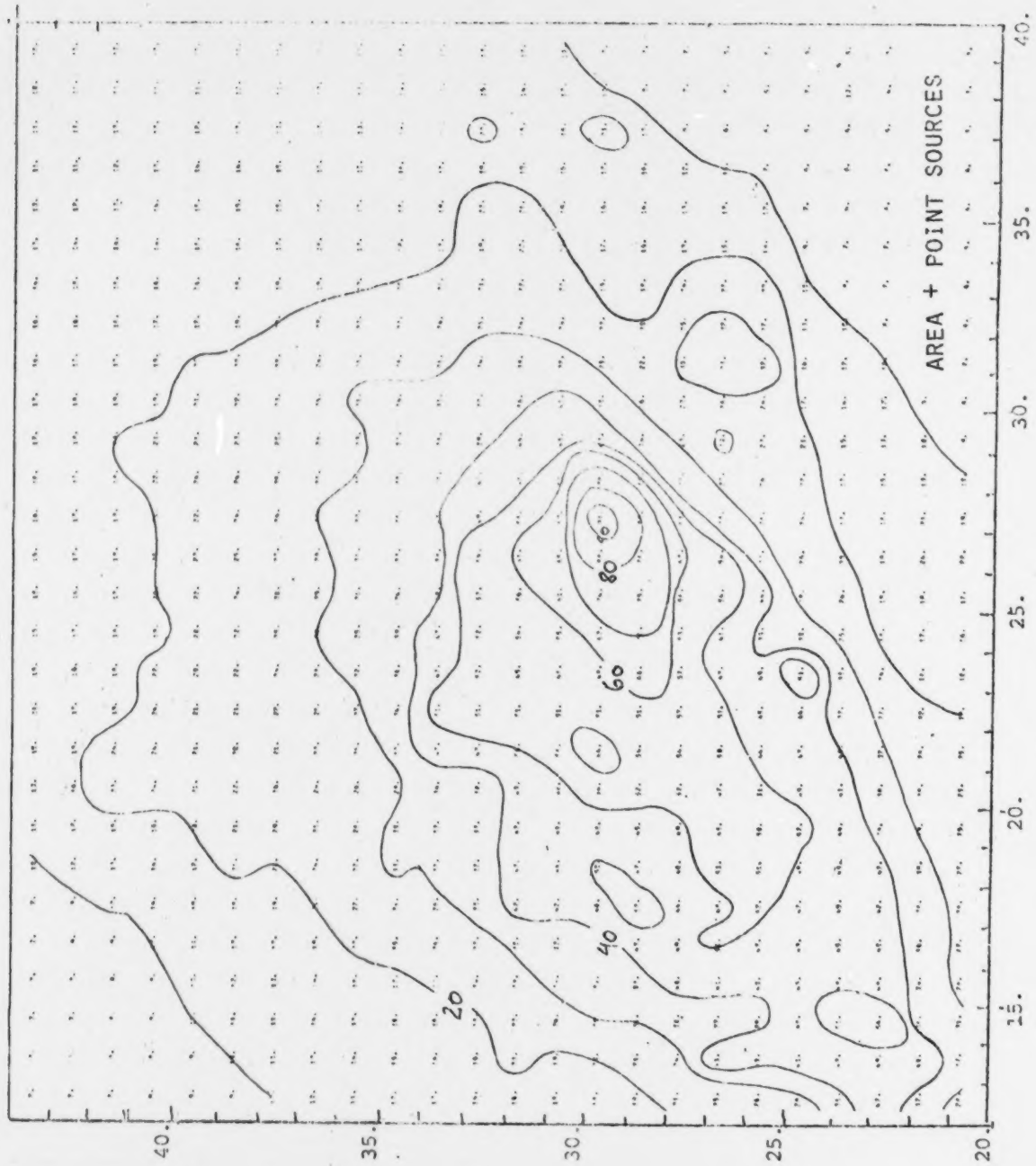

Figure 3: Annual average concentration of SO_2 ($\mu g/m^3$) due to emissions from all sources.

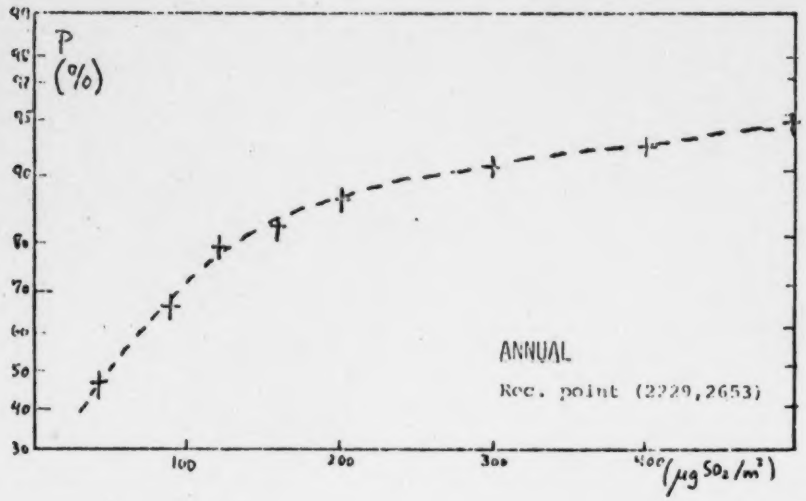

Figure 4: Cumulative frequency distribution of SO_2- concentration calculated at receptor point (2229.2653) on an annual basis.

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Junod, Liechti; Switzerland (Pollux)

Société d'Etude de l'Environnement
under contract of the
Swiss Meteorological Institute

Application of the Multiple Source Dispersion Model POLLUX to the Data of Frankfurt/Main (Test City)

for the NATO Committee of the
Challenges to Modern Society
Expert Panel on Air Pollution Modeling

Air Pollution Pilot Study
Assessment Methodology and Modeling

Pilot Nation: Federal Republic of Germany

Jean-Michel Liechti

Vevey, April 1977

1530 PAYERNE, March 31, 1977
Les Invuardes

Institut Suisse de météorologie
Station aérologique Payerne

Tél. 037 - 61 14 44

Umweltbundesamt
Att. Dr. D. Jost
Bismarckplatz 1

1 BERLIN 33

Deutschland

V/réf.. N/réf.: 76.20 AJd/PJ/aj

NATO/CCMS Air Pollution Pilot Study

Dear Dr. Jost,

You will find herewith our report on the application of the POLLUX dispersion model to the data of Frankfurt, which has been worked out with the collaboration of the SEDE S.A.

We have to mention that a modification of the POLLUX dispersion model was presented at the NATO/CCMS Sixth International Technical Meeting on Air Pollution Modeling and its Application by Mr. A.Scholberg *), who developped these models.

In order to obtain automatically the results required for the pilot study, the POLLUX output routines have been partly modified. Apart of this, the application of POLLUX to the data of Frankfurt has needed about one manmonth, including the preparation of the input data.

Not all possible results of POLLUX are presented in this report. Yearly mean concentrations per dispersion category but for the area sources only are put at your disposal. No sensitivity analysis, for example with respect to dif-

*) "A gaussian model in complex topographical surroundings.
A case study of the dispersion of fluorine from an aluminium plant"

fusion coefficients and meteorological parameters has been performed. On request some additional runs of POLLUX could be done. The option which allows one to model dispersion by wind stagnation conditions (simple box model) has not been used because of the restriction to gaussian models.

POLLUX has been developped for application as well as applied research purposes. Accordingly this model is rather flexible as far as input and computation are concerned. It accepts a list of so called meteorological episodes. An analytical approximated solution for the integration of the point source short term dispersion equation with respect to a varying mean wind direction in a given sector allows one to calculate the concentration for any wind sector and speed. Because of the small number of meteorological episodes used and the retained sector widths, the calculated short term concentrations correspond to a sampling time of the order of several hours and not of the order of $\sqrt{2}$ h. By increasing the number of episodes it would be possible to account for that fact and bring the sampling time of the calculated short term concentrations closer to $\sqrt{2}$ h. The data of the magnetic tape would have given us a better understanding of the time variation of the meteorological parameters, but not of the spatial variation which in our opinion is also necessary for a well differentiated choice of meteorological episodes. In addition to the restricted time at disposal, this has led us to give up handling the data of the tape and consequently increasing the number of meteorological episodes, so that the whole flexibility of POLLUX has not been used.

Because we are often faced in Switzerland with rather complex topographical and meteorological conditions, we think that flexibility is mostly desirable for a dispersion model in order to be able to take these peculiarities into account as far as it is reasonnably possible with such a model. Furthermore, the right choice of representative meteorological episodes to be put in the model needs a good knowledge of the typical meteorological conditions (day and night winds, lake and mountain breezes, calms, precipitations) of the region under consideration.

Yours sincerely
Swiss Meteorological Institute
Vice-Director
A. Junod
Dr. A. Junod.

Application of the Multiple Source Dispersion Model POLLUX to the Data of Frankfurt/Main (Test City)

1. Foreword

The Swiss Meteorological Institute on behalf of the Swiss Political Department accepted the invitation of the German Federal Republic Environment Agency (Umweltbundesamt) to participate to a comparative study on gaussian diffusion models for the assessment of air quality in the case of the Frankfurt Pilot Study, NATO, Committee on the Challenges of Modern Society, Modeling Panel.

The purpose of this study, initiated in 1970, is to model the relationships between pollutant emissions, meteorology and pollutant ground concentrations in a densely populated area. The "Untermain" (fig. 1) with its 1600 km^2 and 1,6 million inhabitants was selected, corresponding to a population density of 1000 people/km^2.

Numerous mesuring and data acquisition campaigns were undertaken. Thus the required SO_2-emission inventory, meteorological data and ground concentration statistics are available for model testing.

The model POLLUX was developped by the Société d'Etude de l'Environnement (SEDE S.A.) Vevey, and partially sponsored by the Swiss Meteorological Institute.

This model is frequently used for air quality studies conducted by the Swiss Meteorological Institute. The computer programme has been written in FORTRAN for the CDC Cyber 7326 computer of the Swiss Federal Institute of Technology, Lausanne (EPFL). The model description can be found in the report: "Multiple Source Model POLLUX, Succint description", SEDE S.A., September 1976.

The present study is based on following documents:

- Technical Document M.P. 2/1975 2.1./2.2.
- Technical Document M.P. 2/1975 2.4.G, Standard Data Base.

- Supplementary Remarks to the Technical Document M.P. 2/1975 2.4.G.
- Magnetband mit den synoptischen Daten der "Test-City", beschrieben in 9-Spur-Verfahren EBCDIC-code.
- Bandbeschreibung dieses Magnetbandes.

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2. Introduction

The following output data are required:

- Yearly means of SO_2-concentration over an aera of 38 x 26 km (988 km^2) with an isopleth line density of 20 µg/-m^3. Grid size can be selected between 500 and 1000 m.
- Yearly means and frequency distribution of SO_2-ground concentrations at 6 selected points.

With this goal, a certain selection has to be made regarding the degree of finesse of the meteorological and emission rate input data retained for computation. In this respect, it should be noted:

- The meteorological data are given in yearly frequencies. (We have not made use of this synoptic data on tape-records because of the time consuming reading work).
- SO_2-Emission-rates are given in seasonal and yearly means. (Monthly values from residential heating can be deduced from monthly degree-days, 1971).

Consequently, the finesse of the input data as used is somewhere reduced in comparison to the overall accuracy of the available data.

Computing time should also be considered. At the computer center of the Federal Institute of Technology, computing is usually limited to 512 sec. per run. This limit had to be extended to 2560 sec. for this study.

Finally, the considered area had to be reduced to 38 x 24 km (912 km^2) because of limited memory space. The grid size (square) was set to 1000 m.

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3. SO_2-Emissions

As usual, SO_2-emitters are divided in elevated, punctual sources and low area sources. Emission data is taken from the available information:

- Listing of 681 punctual sources
- map of area sources (500 x 500 m) with annual emission rate and average building height.

The following adaptations have been made for application of the POLLUX model.

Ponctual sources

- Among the 681 sources all these located outside of the coordinates 900 - 4700/1800 - 4200 have been omitted
- small sources with emission rates below 10 kg/h have been treated as area sources.

With these modifications, the numbers of punctual sources is reduced to 45 units as listed in fig. 2.

For each source the following parameters are defined:

- source name, coordinates, source height, emission rate
- unit plume rise for unstable, neutral, stable and very stable dispersion conditions. Plume rise formula are according to Briggs (1970). Average gas flow was set equal to 50 % of the indicated output. For unstable and neutral conditions the unit plume rise is computed according to

$$E = 1.6 \cdot F^{1/3} x^{2/3}$$

(the maximum plume rise si reached for $x = 6.48F^{2/5} h^{3/5}$.

For stable conditions the formula is:

$$E = 2.9 \cdot F^{1/3} s^{-1/3}$$

with: F : vertical flux

x : downwind distance

s : stability parameter

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A temperature gradient of +1°C/100 m is chosen for stable conditions and +3°C/100 m for very stable conditions.

For ponctual sources the following diffusion parameters as used by the Swiss Meteorological Institute have been selected.

Class	C_y	C_z	m	n
B+C	0,26	0,25	0,14	0,14
D	0,30	0,21	0,36	0,36
E	0,40	0,16	0,52	0,52
F	0,48	0,11	0,58	0,58

Table I

Diffusion coefficients for ponctual sources

Area sources

All sources in the area considered have been retained and grouped in zones of 1 km^2. The programme POLLUX allows for individual area zone definition or "source zone" definition. For the latter all source parameters are identical except for the emission rate. This procedure was selected here. The standard zone is defined by:

- Name, size, height. The selected size is 1000 m and selected height is 10 m
- unit plume rise for unstable, neutral, stable and very stable conditions. It seems reasonable to allow some plume rise to area sources. In POLLUX this is simulated by following formula:

$$\Delta h = \frac{E}{u} \frac{1}{1 + \left(\frac{u}{u_c}\right)^{\nu}}$$

with $u_c = 3$ m/s

$\nu = 2$

For unstable and neutral conditions E is set to 10 m^2/s and to 5 m^2/s for stable and very stable conditions.

- Initial diffusion parameters σ_{yo} and σ_{zo} make allowance for building induced turbulence. The volums selected are:

σ_{yo} = 100 m $\qquad$ σ_{zo} = 10 m

For area sources the so called "St. Louis" diffusion parameters are used:

Class	C_y	C_z	m	n
B	1,64	0,07	0,48	-0,56
C	1,57	0,13	0,52	-0,22
D	2,08	1,05	0,66	0,52
E	0,90	1,22	0,56	0,82

Table II

Diffusion coefficients for area sources

Area source emission rates are mapped in fig. 3.

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4. Meteorology

Meteorological input data are based on "Techn. Doc. M.P. 2/1975 2.4.G Standard Data Base", and on report "5. Arbeitsbericht, Juni 1974, Lufthygienisch-meteorologische Modelluntersuchung in der Region Untermain".

From the results of the large meteo data acquisition campaigns made for the Frankfurt pilot study some remarks may be made:

- During advective situations the wind fields become homogeneous.
- During high pressure situations the nocturnal wind fields are nearly homogeneous and generated by the slope winds of Taunus side valleys, which then turn and flow parallel to the Taunus chain.
- In the South and North-East of Frankfurt the night-wind shows no prevailing direction during high pressure periods.
- By night, the thermal structure of the atmosphere in the center of the town is different from the structure existing at the town periphery while outside of town a ground based inversion is often observed, an unstable layer of 100 m thickness remains in the town center below the inversion.

The "Technical document M.P. 2/1975 2.4.G, Standard Data Base" shows the related frequencies of wind direction, wind speed and stability classes according to TURNER and KLUG.

We have retained the TURNER classification and made an adaptation to the 4 classes considered in the POLLUX Model. The corresponding wind roses are shown in fig. 4 to 8. From these the various meteorological episodes can be defined. In this respect it should be noted:

- The meteorological data are 3 hours average values observed at one single point in the 38 x 28 area
- the emission rates discussed in 3. are annual averages
- the given meteorological data and emission rates are not related.

Taking these considerations into account we have selected with a rather coarse definition 30 meteorological episodes as input data as listed in fig. 9.

Each episode is defined by:

- an average wind speed
- an average wind direction
- a spread angle of the mean wind direction
- a stability class
- a frequency of occurrence

No information on mixing height is available. Its value has therefore been set to infinity.

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5. Results

Required are:

- Spatial distribution of yearly means of SO_2 concentration with a isopleth line density of 20 $\mu g/m^3$
- yearly mean and frequency distribution of short term ground concentrations (1/2 to 1 h) at 6 selected points.

With the input of emission rate data and meteo data as described in 3 and 4, the POLLUX Model required about 15 minutes computing time and produced the following results:

- Spatial distribution of annual means of SO_2 concentration

  The yearly isopleth lines are mapped in fig. 10. The annual mean value at each grid point are listed in fig. 11. The maximum concentration is 96,5 $\mu g/m^3$. The spatial distribution of ground concentrations follows in general the emission density distribution, the main meteorological effect being governed by the winds blowing parallel to the Taunus chain.

- Short term ground concentrations frequency distribution at 6 selected points

  The 6 selected points are shown on the map of fig. 10. The average values and distributions were not actually completed from one single grid point but from 9 points within an area of 2 x 2 km. giving a total of 270 values from 30 episodes. Trials did show that statistics from smaller reference zones were not satisfactory.

  The frequency distributions obtained are plotted on a lognormal grid in fig. 12 to 17. They depend essentially on the location of the point with respect to the center of Frankfurt.
  Points C, D and E are in the main agglomeration while points A, B and F are on the perisphery. The mean, mode and 95 % value are given in following table.

	mean	50 %	95 %
Pt A (1600, 2700)	57	30	220
Pt B (1900, 3200)	37	22	130
Pt C (2229, 2653)	62	32	230
Pt D (2476, 2898)	79	47	280
Pt E (2825, 2815)	57	36	200
Pt F (3400, 2700)	28	17	90

Table III

SO_2 ground concentrations ($\mu g/m^3$)

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6. Conclusions

It is difficult to appraise the results obtained with the POLLUX model without knowledge of the actual measured concentration values.

- There are reasons to believe that the computed concentrations are rather underestimated. For instance the emission rates from domestic heating, calculated from heat demand, are obtained by assuming combustion efficiencies that are much higher than in reality (the emission from domestic heating assumed in Switzerland are much higher. Furthermore, "imported" pollution has not been considered.
  From the meteorological point of view, only stationary and homogeneous wind fields have been considered, while episodes like calms, elevated inversions, fumigations which conduct to the highest concentrations are not included.

  On the other hand it must also be said that SO_2 elimination or transformation processes have not been taken into account.

- Regarding the representativity of the computed concentrations, it is to expect, that the contrast of concentrations is much less pronounced than in reality.
  The main reason for that is the fact that emission rates and meteorological episodes used are not related. Similarly the variation of short term concentrations is flattened out, particularly at the high level end, by using yearly average values and a rather coarse set of meteorological episodes. Finally a doubt subsists on the applicability of the selected diffusion coefficients to the Frankfurt area, particularly with respect to very elevated sources and long distances.

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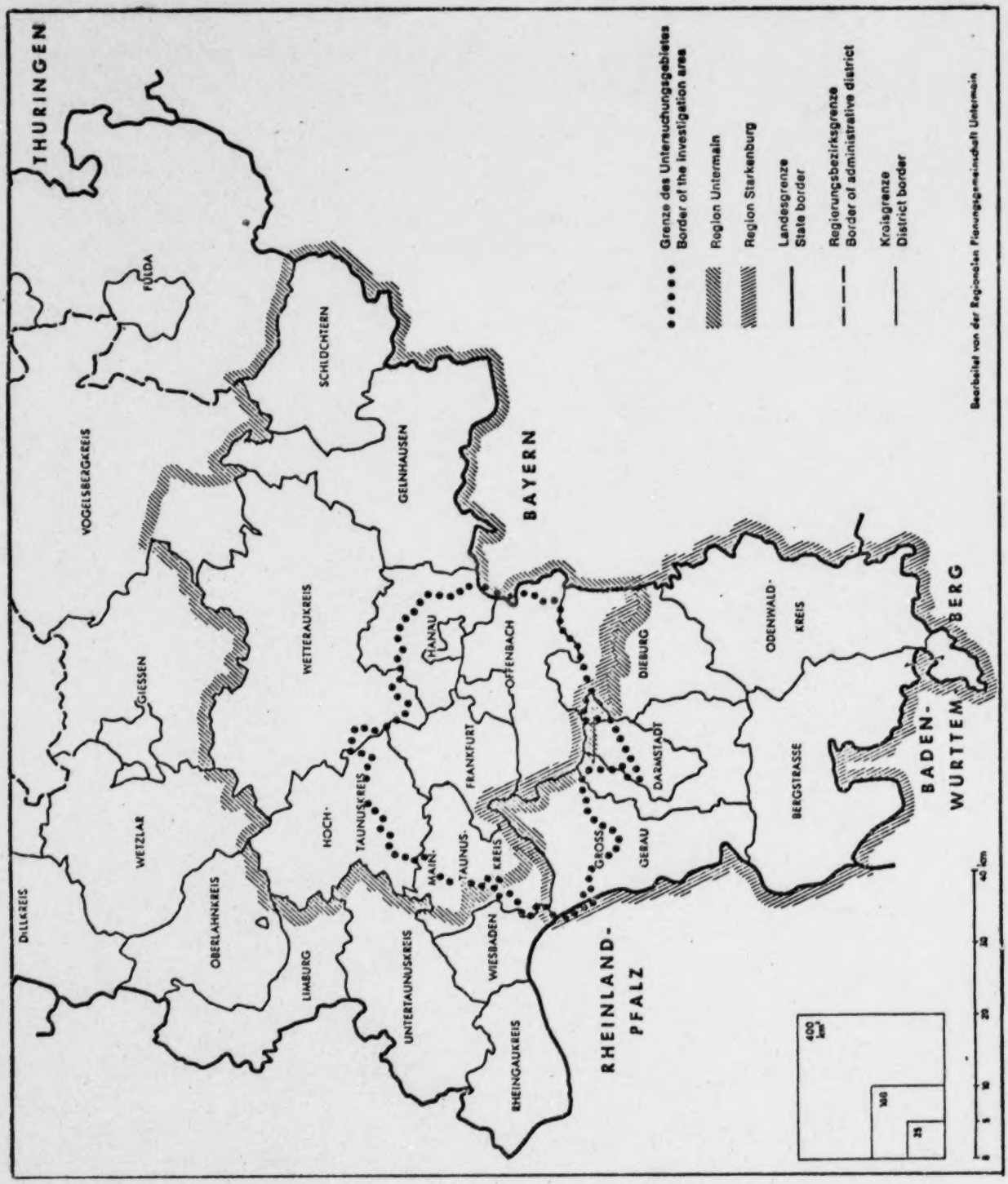

Figure 1

(source: 5. Arbeitsbericht, Juni 1974, Lufthygienisch- meteorologische Modelluntersuchung in der Region Untermain)

SOURCE			Q (g/s)	HAUTEUR (m)	X (m)	Y (m)	LARGEUR (m)	INSTABLE (m^2/s)	NEUTRE (m^2/s)	STABLE (m^2/s)	STABLE++ (m^2/s)	SGO Y (m)	SGO Z (m)	A0	A1	A2
PUNKT	1	1	26.70	90.	14780.	22000.	0.	163.	163.	79.	63.	0.	0.	0.00	0.00	1.00
PUNKT	2	2	464.60	145.	11900.	19520.	0.	1299.	1299.	225.	181.	0.	0.	0.00	0.00	1.00
PUNKT	3	3	118.10	109.	11740.	19370.	0.	334.	334.	114.	91.	0.	0.	0.00	0.00	1.00
PUNKT	4	4	13.50	89.	11600.	19330.	0.	160.	160.	83.	66.	0.	0.	0.00	0.00	1.00
PUNKT	5	5	35.40	109.	11870.	19320.	0.	346.	346.	115.	92.	0.	0.	0.00	0.00	1.00
PUNKT	6	6	13.90	109.	11710.	19240.	0.	173.	173.	79.	63.	0.	0.	0.00	0.00	1.00
PUNKT	7	7	636.00	119.	11690.	19290.	0.	496.	496.	138.	11[illegible].	0.	0.	0.00	0.00	1.00
PUNKT	59	8	3.40	60.	19690.	42000.	0.	50.	50.	45.	36.	0.	0.	0.00	0.00	1.00
PUNKT	60	9	3.10	45.	21370.	39670.	0.	46.	46.	29.	23.	0.	0.	0.00	0.00	1.00
PUNKT	63	10	3.70	25.	23550.	34100.	0.	64.	64.	63.	50.	0.	0.	0.00	0.00	1.00
PUNKT	64	11	3.70	25.	23550.	34100.	0.	63.	63.	62.	50.	0.	0.	0.00	0.00	1.00
PUNKT	65	12	90.90	110.	23050.	33450.	0.	444.	444.	133.	106.	0.	0.	0.00	0.00	1.00
PUNKT	70	13	7.80	100.	32290.	29870.	0.	117.	117.	64.	51.	0.	0.	0.00	0.00	1.00
PUNKT	73	14	46.20	82.	44880.	29110.	0.	191.	191.	89.	70.	0.	0.	0.00	0.00	1.00
PUNKT	76	15	4.00	76.	47100.	26020.	0.	80.	80.	56.	45.	0.	0.	0.00	0.00	1.00
PUNKT	79	16	20.80	77.	43300.	28150.	0.	46.	46.	41.	33.	0.	0.	0.00	0.00	1.00
PUNKT	80	17	5.00	42.	26870.	28090.	0.	65.	65.	55.	45.	0.	0.	0.00	0.00	1.00
PUNKT	81	18	46.50	93.	43660.	28020.	0.	298.	298.	110.	88.	0.	0.	0.00	0.00	1.00
PUNKT	90	19	55.50	92.	24270.	26450.	0.	215.	215.	92.	74.	0.	0.	0.00	0.00	1.00
PUNKT	91	20	48.80	84.	24270.	26450.	0.	248.	248.	102.	82.	0.	0.	0.00	0.00	1.00
PUNKT	92	21	58.00	120.	24270.	26450.	0.	327.	327.	109.	87.	0.	0.	0.00	0.00	1.00
PUNKT	93	22	19.20	88.	27220.	26420.	0.	126.	126.	69.	55.	0.	0.	0.00	0.00	1.00
PUNKT	94	23	14.00	70.	24120.	26300.	0.	139.	139.	75.	61.	0.	0.	0.00	0.00	1.00
PUNKT	95	24	21.70	80.	16460.	26230.	0.	207.	207.	93.	74.	0.	0.	0.00	0.00	1.00
PUNKT	96	25	16.00	90.	16460.	26230.	0.	155.	155.	77.	62.	0.	0.	0.00	0.00	1.00
PUNKT	97	26	5.00	45.	27060.	26090.	0.	61.	61.	53.	42.	0.	0.	0.00	0.00	1.00
PUNKT	99	27	53.30	80.	19680.	25850.	0.	197.	197.	88.	70.	0.	0.	0.00	0.00	1.00
PUNKT	101	28	23.50	83.	19640.	25600.	0.	147.	147.	75.	61.	0.	0.	0.00	0.00	1.00
PUNKT	102	29	63.00	90.	15570.	25710.	0.	335.	335.	115.	94.	0.	0.	0.00	0.00	1.00
PUNKT	103	30	6.00	137.	15570.	25710.	0.	210.	210.	83.	66.	0.	0.	0.00	0.00	1.00
PUNKT	104	31	210.00	100.	15570.	25710.	0.	455.	455.	137.	110.	0.	0.	0.00	0.00	1.00
PUNKT	106	32	164.70	195.	45840.	25260.	0.	799.	799.	161.	129.	0.	0.	0.00	0.00	1.00
PUNKT	107	33	209.30	195.	45780.	25260.	0.	805.	805.	162.	130.	0.	0.	0.00	0.00	1.00
PUNKT	108	34	23.10	195.	45700.	25250.	0.	755.	755.	155.	125.	0.	0.	0.00	0.00	1.00
PUNKT	109	35	10.90	100.	14840.	25140.	0.	290.	290.	105.	75.	0.	0.	0.00	0.00	1.00
PUNKT	111	36	95.90	100.	22450.	24960.	0.	535.	535.	151.	120.	0.	0.	0.00	0.00	1.00
PUNKT	447	37	3.50	65.	45880.	28450.	0.	102.	102.	65.	52.	0.	0.	0.00	0.00	1.00
PUNKT	465	38	11.90	120.	33410.	27320.	0.	102.	102.	56.	46.	0.	0.	0.00	0.00	1.00
PUNKT	485	39	25.10	120.	33410.	27310.	0.	179.	179.	78.	62.	0.	0.	0.00	0.00	1.00
PUNKT	493	40	4.40	110.	32260.	23710.	0.	230.	230.	91.	73.	0.	0.	0.00	0.00	1.00
PUNKT	529	41	3.60	41.	43860.	26760.	0.	48.	48.	48.	38.	0.	0.	0.00	0.00	1.00
PUNKT	606	42	7.00	67.	15480.	32000.	0.	75.	75.	55.	44.	0.	0.	0.00	0.00	1.00
PUNKT	613	43	6.10	67.	15470.	32990.	0.	84.	84.	59.	47.	0.	0.	0.00	0.00	1.00
PUNKT	621	44	11.30	100.	13120.	21100.	0.	125.	125.	65.	53.	0.	0.	0.00	0.00	1.00
PUNKT	622	45	12.40	100.	12600.	20860.	0.	98.	98.	58.	46.	0.	0.	0.00	0.00	1.00

Figure 2

Listing of punctual sources

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4200 900 4700

0	0	0	0	0	0	0	0	0	5	15	215	224	90	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	5	13	3	140	133	140	153	0	45	96	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	8	60	147	64	0	33	18	111	90	65	0	0	0	0	0	0	0	0	12	39	0	0	0	0	0	0	0	0	0	0	0	0
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0	1	26	13	0	0	0	0	0	74	133	131	0	0	0	0	186	29	37	48	0	0	0	0	5	25	16	29	17	84	23	0	0	69	4	14	13	3
7	65	56	20	74	43	37	28	4	94	50	57	0	19	58	56	91	3	41	0	77	85	3	0	17	36	12	3	0	0	0	0	0	0	35	25	6	4
2	42	101	44	72	156	38	64	0	15	89	66	0	0	88	48	106	9	65	0	40	159	24	0	0	0	0	0	0	0	0	20	44	40	123	0	0	0
38	43	3	0	16	14	38	0	0	150	125	1	71	5	73	22	78	36	21	71	196	47	0	0	0	0	0	0	0	45	26	2	6	0	98	0	0	0
0	1	23	67	2	1	0	78	17	17	13	0	245	287	361	338	101	130	139	0	41	0	36	1	0	0	0	0	0	14	7	0	0	0	0	0	18	61
24	4	21	50	75	1	6	97	15	0	0	0	164	298	124	349	373	349	154	0	0	42	202	0	0	53	141	16	39	0	0	10	0	9	0	17	0	0
126	33	0	43	169	37	105	91	156	160	18	65	201	186	72	391	408	298	290	23	225	71	364	28	0	95	69	0	15	5	2	24	53	109	79	252	0	0
193	58	0	43	61	79	144	8	24	8	29	1	187	123	76	144	371	205	758	356	31	219	138	106	0	67	0	0	308	194	5	1	103	152	306	113	8	0
14	107	33	36	0	13	25	0	45	180	18	226	411	148	511	164	557	937	1064	926	108	211	47	207	25	43	7	71	90	83	13	56	73	115	445	121	7	30
0	0	0	47	0	0	92	113	253	73	0	131	70	139	573	668	667	660	573	620	80	306	7	137	267	0	94	90	162	60	30	11	18	181	97	42	43	105
0	0	0	0	0	0	307	471	51	35	88	41	58	299	305	227	335	509	344	213	10	173	372	267	503	189	46	0	97	3	0	0	0	160	24	62	146	44
1	0	0	84	291	13	245	314	158	168	140	273	228	428	262	139	435	585	136	12	197	31	501	279	465	54	0	0	0	87	11	0	0	8	68	82	180	24
141	51	97	0	157	84	5	14	0	197	145	252	261	177	236	116	361	76	8	37	0	72	376	163	269	166	181	0	0	29	20	0	0	0	13	20	0	0
158	76	54	0	0	201	4	3	0	62	136	162	134	171	409	114	172	94	2	0	0	14	114	144	153	47	114	7	0	49	154	2	0	0	0	84	22	54
0	0	45	206	40	1	71	0	0	0	0	0	0	7	12	0	6	0	0	0	0	0	0	0	0	0	0	0	68	80	86	0	0	0	13	83	11	104
0	0	0	94	0	34	171	26	0	0	0	0	0	0	0	0	0	0	2	1	2	0	0	0	13	10	44	21	36	34	0	1	0	0	0	0	0	0
0	29	0	49	71	23	114	0	0	0	37	17	0	0	0	30	47	289	234	60	7	0	3	0	58	201	81	5	20	54	0	116	60	0	2	175	6	7
0	19	33	5	0	0	0	0	4	0	0	0	0	0	0	0	33	265	246	79	0	0	0	0	3	32	0	0	0	67	2	76	6	0	0	0	0	109
1	40	25	3	0	0	0	0	0	0	3	3	71	0	0	0	0	71	76	0	0	0	0	0	13	3	0	0	0	0	14	28	12	0	0	0	0	54
0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	5	77	34	164	14	0	0	0	0	22	71	0	0	0	0	0	164	38	0	0	0	0	1

1800

Figure 3

Map of the area sources SO_2-emission rates (10^{-2}g/s)

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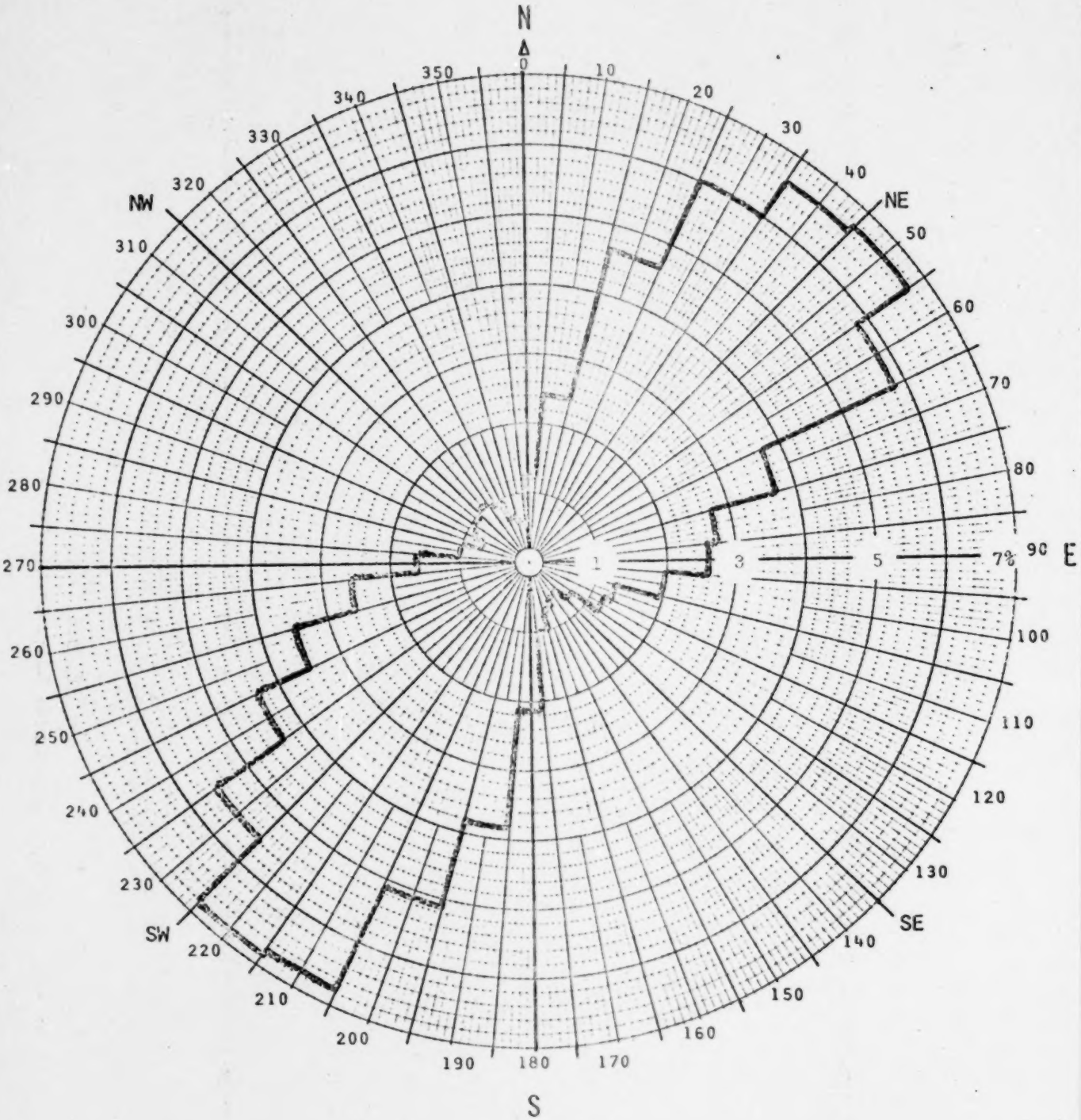

Figure 4

Windrose, all stability classes (8.71-7.72)
(100 %)

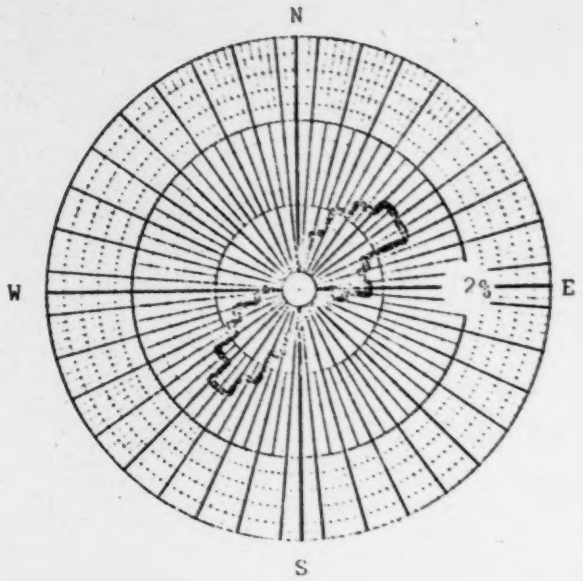

Figure 5

Windrose, unstable conditions
(21.5 %)

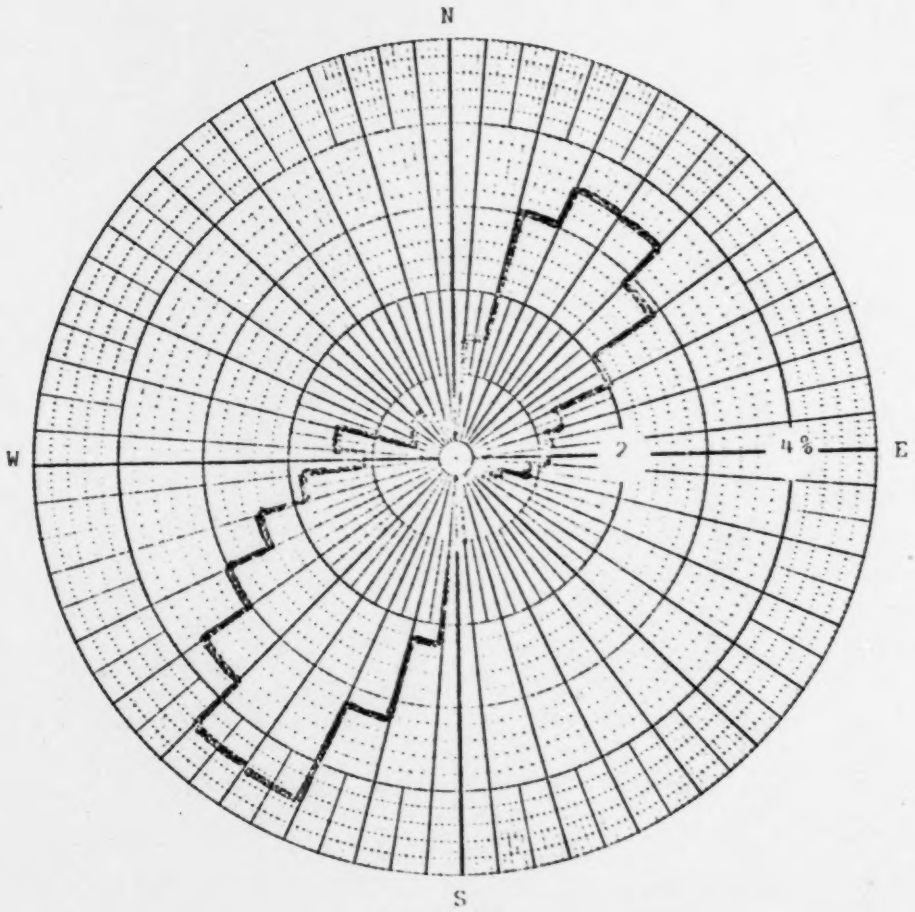

Figure 6

Windrose, neutral conditions
(55.8 %)

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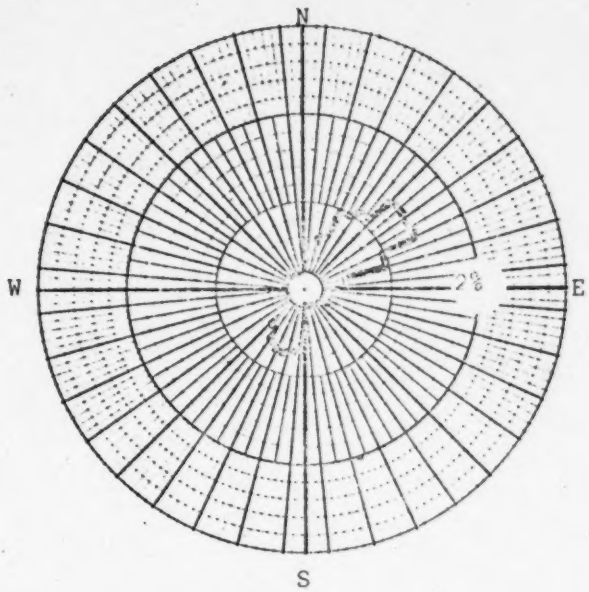

Figure 7

Windrose, stable conditions
(14.5 %)

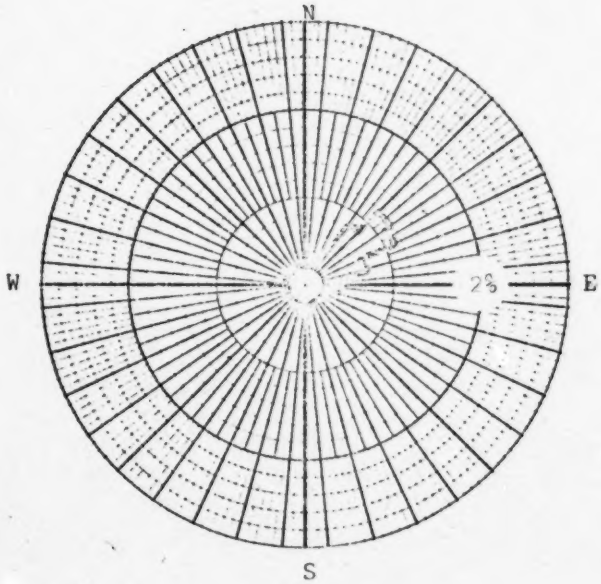

Figure 8

Windrose, very stable conditions
(8.2 %)

EPISODE		CLASSE	VITESSE (m/s)	DIRECT. (°)	SECTEUR (°)	PLAFOND* (m)	PROB. (%)	EMISSION
LAB 20	1	INSTABLE	2.4	20.	30.	0.	3.	1.0
LAB 50	2	INSTABLE	2.7	50.	30.	0.	4.	1.0
LAB 85	3	INSTABLE	2.2	85.	40.	0.	3.	1.0
LAB 130	4	INSTABLE	2.0	130.	50.	0.	2.	1.0
LAB 190	5	INSTABLE	2.3	190.	30.	0.	2.	1.0
LAB 220	6	INSTABLE	2.8	220.	30.	0.	4.	1.0
LAB 250	7	INSTABLE	2.7	250.	30.	0.	2.	1.0
LAB 290	8	INSTABLE	3.2	290.	50.	0.	2.	1.0
NEU 20	9	NEUTRE	4.8	20.	10.	0.	3.	1.0
NEU 35	10	NEUTRE	4.8	35.	20.	0.	7.	1.0
NEU 50	11	NEUTRE	3.6	50.	10.	0.	3.	1.0
NEU 60	12	NEUTRE	2.8	60.	10.	0.	2.	1.0
NEU 90	13	NEUTRE	2.0	90.	50.	0.	5.	1.0
NEU 170	14	NEUTRE	2.6	170.	30.	0.	2.	1.0
NEU 190	15	NEUTRE	3.4	190.	10.	0.	2.	1.0
NEU 200	16	NEUTRE	3.9	200.	10.	0.	3.	1.0
NEU 215	17	NEUTRE	4.6	215.	20.	0.	9.	1.0
NEU 230	18	NEUTRE	5.8	230.	10.	0.	4.	1.0
NEU 240	19	NEUTRE	6.0	240.	10.	0.	3.	1.0
NEU 255	20	NEUTRE	5.7	255.	20.	0.	4.	1.0
NEU 275	21	NEUTRE	4.9	275.	20.	0.	2.	1.0
NEU 315	22	NEUTRE	3.8	315.	40.	0.	4.	1.0
NEU 5	23	NEUTRE	3.6	5.	20.	0.	2.	1.0
STA 30	24	STABLE	1.9	30.	30.	0.	4.	1.0
STA 60	25	STABLE	1.8	60.	30.	0.	4.	1.0
STA 100	26	STABLE	1.5	100.	50.	0.	2.	1.0
STA 200	27	STABLE	1.6	200.	50.	0.	5.	1.0
STA+ 40	28	STABLE++	1.0	40.	30.	0.	3.	1.0
STA+ 80	29	STABLE++	1.0	80.	50.	0.	4.	1.0
STA+ 200	30	STABLE++	1.0	200.	50.	0.	2.	1.0

Figure 9

Listing of meteorological episodes
(* mixing height = m)

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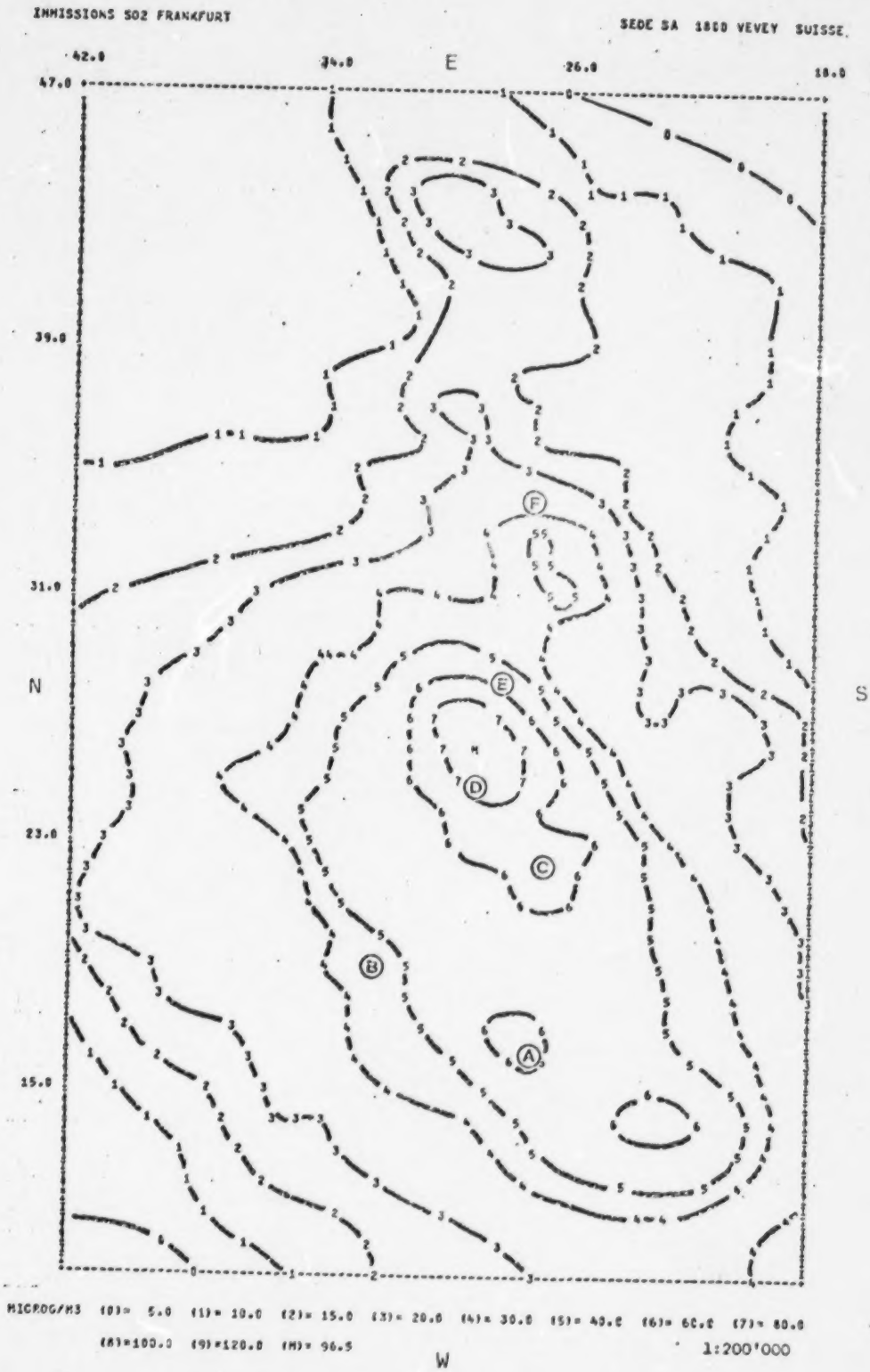

Figure 10

Annual mean concentrations

IMMISSIONS SO2 FRANKFURT

SEDE SA 1800 VEVEY SUISSE

Y	42000.	41000.	40000.	39000.	38000.	37000.	36000.	35000.	34000.	33000.	32000.	31000.	30000.
47000.	5.55	5.63	5.93	6.24	6.58	7.04	7.67	8.61	10.11	10.78	11.35	11.47	11.38
46000.	5.64	5.84	5.98	6.30	6.77	7.11	7.46	8.15	10.15	12.11	12.48	14.53	14.68
45000.	5.69	5.91	6.17	6.38	7.05	7.70	7.58	7.73	9.08	11.20	14.60	15.96	16.26
44000.	5.47	5.66	5.92	6.30	6.80	8.04	9.09	8.84	8.45	9.81	15.71	22.19	23.66
43000.	5.48	5.60	5.81	6.19	7.16	7.66	9.69	10.98	9.53	8.39	11.73	18.77	26.09
42000.	5.29	5.31	5.40	5.61	6.79	7.74	7.96	8.42	7.50	7.37	10.13	15.12	19.27
41000.	5.65	5.64	5.69	5.78	6.11	6.65	7.72	8.01	7.25	6.99	8.38	11.77	15.26
40000.	6.22	6.20	6.26	6.54	6.61	6.59	7.25	7.95	7.51	7.72	8.77	10.18	11.98
39000.	7.14	6.80	6.78	7.30	8.34	7.71	7.35	8.43	9.00	8.83	9.95	12.37	13.21
38000.	7.32	7.68	7.33	7.59	9.01	9.37	8.12	8.69	9.96	10.44	11.38	17.12	19.24
37000.	8.36	8.51	8.38	8.20	9.90	9.17	8.65	8.85	9.80	11.03	12.52	17.26	22.12
36000.	8.95	9.24	9.46	9.51	9.80	10.10	9.62	9.49	10.18	12.65	13.74	14.74	17.35
35000.	9.61	10.05	10.72	10.92	11.38	11.55	11.09	10.88	11.04	14.54	18.23	17.89	18.44
34000.	10.86	11.09	11.86	12.46	12.63	13.56	13.04	12.23	12.58	14.05	17.61	19.84	21.07
33000.	12.36	12.22	12.72	13.06	13.49	14.34	14.83	14.30	14.62	15.53	16.60	19.15	21.54
32000.	13.47	13.61	13.44	13.84	14.56	15.48	16.29	16.96	17.46	19.79	22.58	22.24	23.76
31000.	14.78	14.84	15.20	15.16	16.04	17.80	20.10	20.38	20.69	24.12	30.39	32.63	28.40
30000.	15.67	16.23	16.45	17.11	17.31	20.05	24.06	26.56	24.47	25.34	30.18	33.61	35.09
29000.	15.95	17.23	18.18	18.83	19.90	20.98	23.65	28.05	30.11	29.29	35.50	42.66	47.07
28000.	16.34	17.60	19.22	21.02	22.65	24.06	24.56	27.71	31.91	34.19	40.03	55.12	73.45
27000.	16.57	18.69	19.80	21.73	24.46	25.93	27.94	29.65	34.35	41.36	47.75	62.35	83.11
26000.	16.17	19.03	20.93	21.83	26.18	28.73	29.20	31.30	34.90	44.29	53.40	58.87	77.39
25000.	15.94	17.78	20.15	21.08	25.56	31.76	34.12	35.44	38.75	45.61	55.48	59.65	68.94
24000.	16.03	18.44	20.18	20.80	21.74	26.23	31.53	38.57	41.27	47.15	50.58	53.35	59.49
23000.	16.36	20.12	22.60	20.04	19.16	21.63	26.03	29.95	42.85	49.53	47.00	47.59	56.52
22000.	18.16	22.56	23.82	20.89	18.71	19.58	21.73	26.04	37.19	49.10	52.14	51.63	54.47
21000.	19.04	24.16	22.01	20.74	19.91	20.15	21.49	24.94	33.08	41.58	47.83	50.84	57.73
20000.	16.37	21.93	21.75	20.70	22.31	23.42	23.84	25.64	28.08	32.50	38.43	44.63	49.23
19000.	13.25	16.56	18.35	20.99	23.59	24.22	24.29	26.44	29.79	30.49	35.64	40.96	47.54
18000.	11.42	13.88	17.22	20.28	22.23	22.70	23.50	26.56	29.85	29.86	35.49	41.08	47.43
17000.	9.98	11.47	15.44	18.30	18.20	19.47	21.62	23.87	27.19	29.76	33.74	38.09	41.98
16000.	9.07	10.11	12.66	15.12	15.89	17.83	20.61	22.77	25.13	28.74	31.81	34.50	36.06
15000.	8.27	9.15	10.68	12.42	13.91	16.28	19.70	20.34	20.78	22.58	28.07	33.33	33.99
14000.	6.81	7.65	8.93	10.34	11.80	14.80	19.00	20.52	19.13	21.47	25.57	28.75	29.58
13000.	5.99	6.76	7.80	8.96	10.35	13.03	16.59	17.74	18.22	20.42	24.49	27.15	26.79
12000.	5.57	6.27	7.09	8.06	9.76	12.00	14.72	15.28	16.35	18.32	19.56	21.58	23.05
11000.	5.17	5.80	6.41	7.22	8.74	11.53	14.10	14.76	13.93	15.44	17.01	17.37	19.36
10000.	3.49	3.90	4.30	4.91	5.75	7.93	10.45	11.86	12.17	12.85	15.75	17.87	19.02
9000.	2.86	3.21	3.59	4.08	4.80	6.18	7.87	9.45	10.75	11.60	14.46	17.90	18.63

Figure 11a

Listing of annual mean concentrations (ug/m^3)

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Y	29000.	28000.	27000.	26000.	25000.	24000.	23000.	22000.	21000.	20000.	19000.	18000.
47000.	10.59	9.72	7.39	4.62	4.34	4.06	2.64	2.12	2.73	2.28	1.24	.83
46000.	13.34	13.81	10.32	6.16	5.13	6.14	5.11	2.76	3.34	5.09	3.54	2.03
45000.	12.99	12.33	14.90	11.50	7.34	6.59	6.59	7.05	5.26	4.16	3.65	2.87
44000.	22.64	16.04	15.81	10.79	8.99	10.78	9.90	9.88	10.02	6.33	4.97	3.87
43000.	25.76	19.58	19.63	16.15	11.75	10.32	10.48	9.67	8.79	7.30	5.71	4.91
42000.	20.55	22.63	21.66	16.57	13.50	11.29	11.00	10.90	9.60	8.40	7.07	5.60
41000.	16.67	16.10	15.87	15.61	13.55	11.80	11.20	12.74	12.45	10.02	9.99	7.78
40000.	14.44	13.71	13.59	14.55	14.69	13.09	11.11	12.25	13.42	11.59	11.36	10.74
39000.	13.52	13.26	13.05	13.66	15.59	16.68	13.25	11.12	11.06	10.29	9.31	8.49
38000.	16.87	15.27	13.19	13.45	13.71	15.17	14.24	12.01	11.74	10.68	9.06	8.05
37000.	20.03	18.49	14.62	12.21	12.03	12.85	13.53	11.71	10.26	9.40	8.62	7.88
36000.	20.48	18.64	14.88	14.57	13.70	12.25	12.15	12.07	9.87	8.95	8.20	7.71
35000.	21.00	22.46	18.18	18.05	16.41	14.37	12.23	14.33	12.36	9.19	8.80	7.87
34000.	24.30	29.58	28.30	23.14	20.39	14.48	11.88	14.13	14.37	10.51	9.90	9.24
33000.	26.03	35.75	40.59	36.13	27.51	18.55	12.75	12.37	11.93	10.31	9.59	8.94
32000.	25.90	33.32	40.76	38.73	29.91	21.14	14.74	12.52	10.67	9.80	9.14	8.61
31000.	27.40	31.79	39.37	41.03	33.41	23.01	17.00	13.71	11.59	10.10	9.25	8.59
30000.	33.93	33.49	31.75	28.54	26.14	21.85	18.34	15.06	12.56	10.70	9.37	8.83
29000.	44.84	35.82	30.79	27.81	22.53	21.19	18.96	16.82	14.64	12.07	10.25	9.03
28000.	77.30	59.35	41.15	27.36	21.72	20.35	19.29	20.45	20.36	16.33	13.21	10.19
27000.	93.81	75.95	57.54	36.38	26.64	21.80	19.53	24.38	27.73	22.27	17.06	13.96
26000.	96.53	88.32	75.70	57.02	38.41	26.60	20.51	22.17	26.94	23.43	18.02	13.81
25000.	85.73	86.95	74.31	60.17	46.14	30.26	22.24	20.40	20.91	18.94	17.09	15.03
24000.	72.31	75.60	62.90	54.05	51.47	37.84	26.91	23.38	21.30	18.10	16.34	14.68
23000.	69.86	73.07	66.39	61.64	60.80	49.06	32.94	26.65	22.77	19.91	16.54	14.93
22000.	58.06	59.92	67.81	63.62	55.45	47.11	36.92	30.98	26.19	22.11	18.65	16.21
21000.	59.20	55.28	62.78	61.99	55.22	46.64	38.80	33.08	28.53	24.18	20.95	17.84
20000.	55.15	55.83	57.64	56.57	53.14	44.72	39.36	34.96	30.56	25.23	21.52	19.23
19000.	49.59	52.18	54.27	54.10	56.79	48.90	41.41	36.12	32.40	27.02	22.31	19.41
18000.	56.68	56.82	56.51	57.73	51.84	49.25	42.13	36.59	33.18	27.78	22.42	19.86
17000.	53.58	65.75	65.86	55.78	48.11	45.78	42.66	36.99	33.23	29.75	23.35	20.22
16000.	43.08	57.44	65.56	54.30	49.65	49.39	47.70	42.28	36.08	32.71	25.01	19.71
15000.	34.84	43.07	52.07	53.00	55.46	59.47	60.06	54.44	43.78	36.29	28.70	20.70
14000.	29.75	34.79	43.23	48.94	53.46	62.33	62.82	63.84	55.10	41.03	27.93	24.95
13000.	27.61	30.33	38.09	46.90	45.75	51.74	54.59	58.07	58.43	39.56	27.06	23.38
12000.	24.14	25.41	29.98	34.84	35.19	39.21	45.53	43.73	39.42	29.57	23.46	20.15
11000.	20.58	20.98	24.59	27.97	29.95	29.15	30.59	29.09	27.22	26.70	26.56	36.08
10000.	19.62	19.75	21.34	24.49	27.07	26.44	24.68	26.59	27.74	27.32	32.51	44.23
9000.	17.38	18.58	19.13	21.79	24.70	23.91	22.02	23.55	24.09	29.24	31.17	35.09

Figure 11b

Listing of annaul mean concentrations ($\mu g/m^3$)

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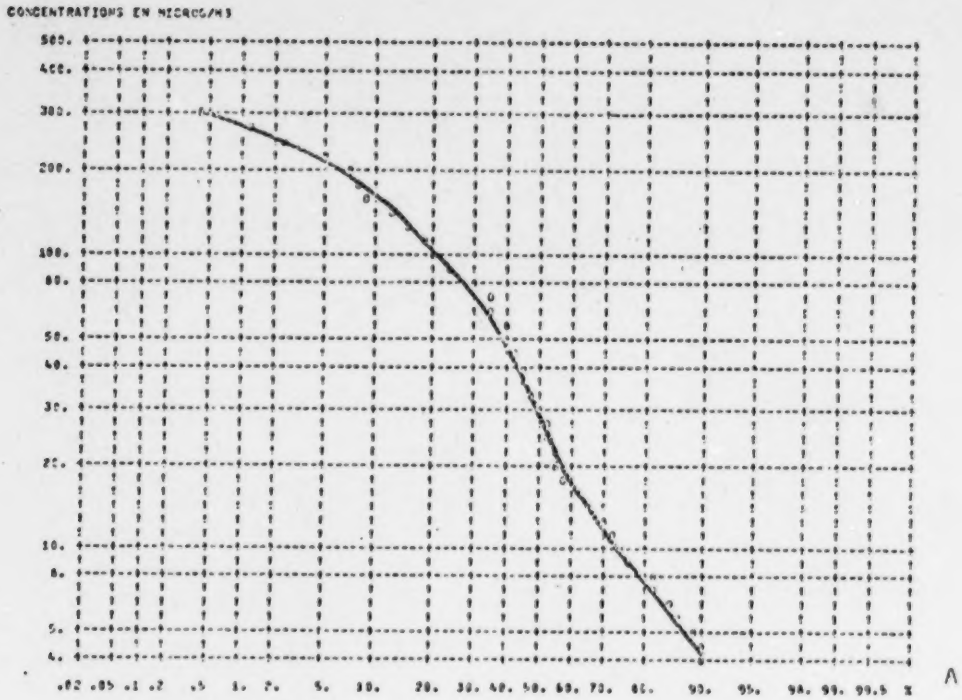
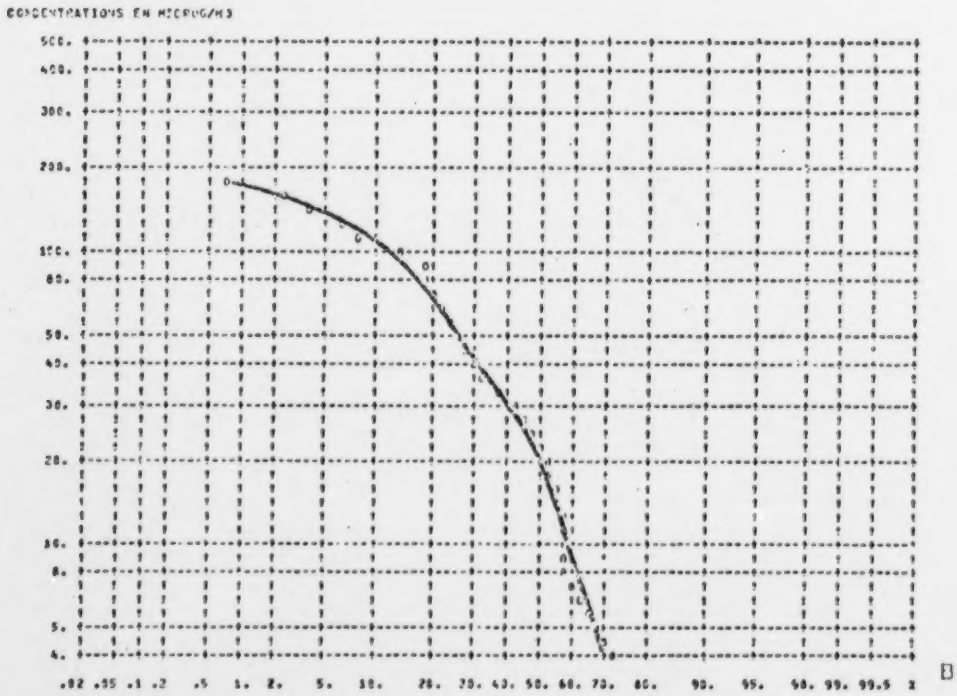
sede sa



A

Figure 12

Frequency distribution of short term concentrations, Point A

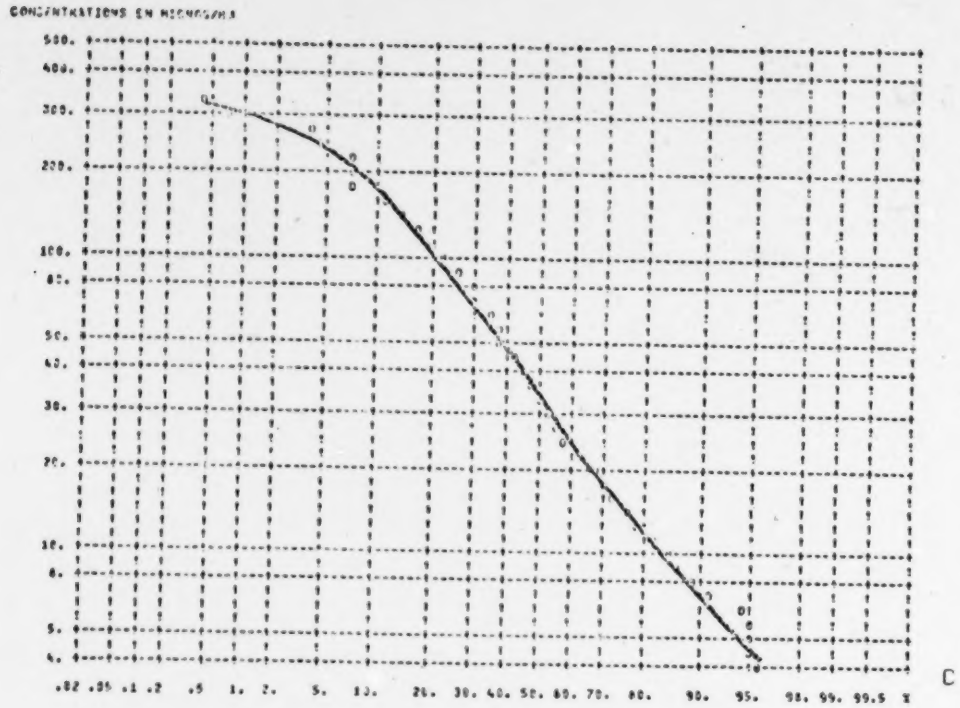


B

Figure 13

Frequency distribution of short term concentrations, Point B

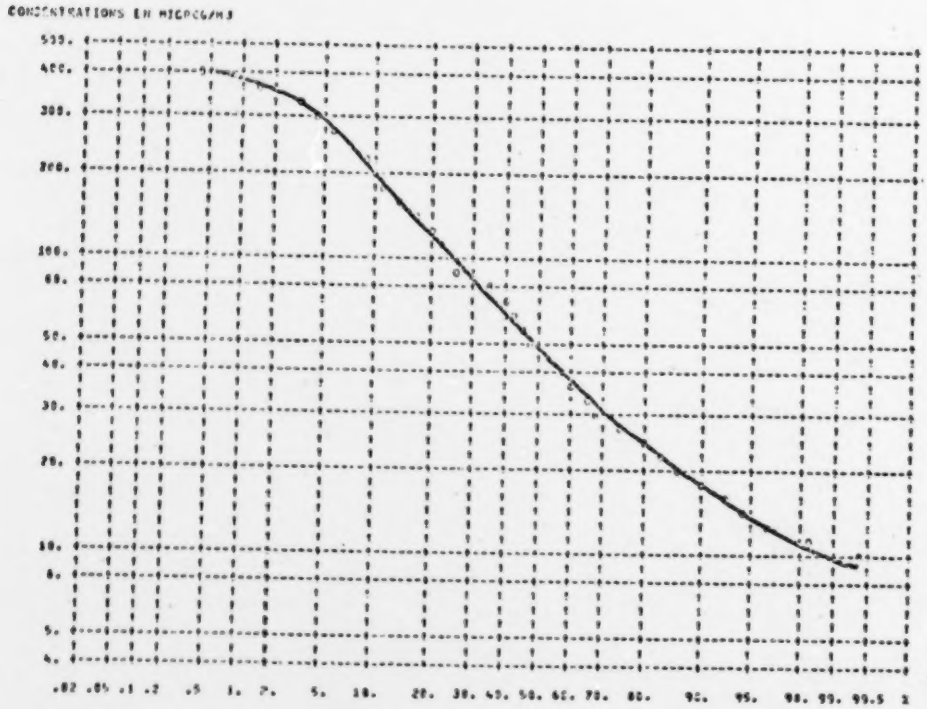
sede sa



C

Figure 14

Frequency distribution of short term concentrations, Point C



D

Figure 15

Frequency distribution of short term concentrations, Point D

sede sa

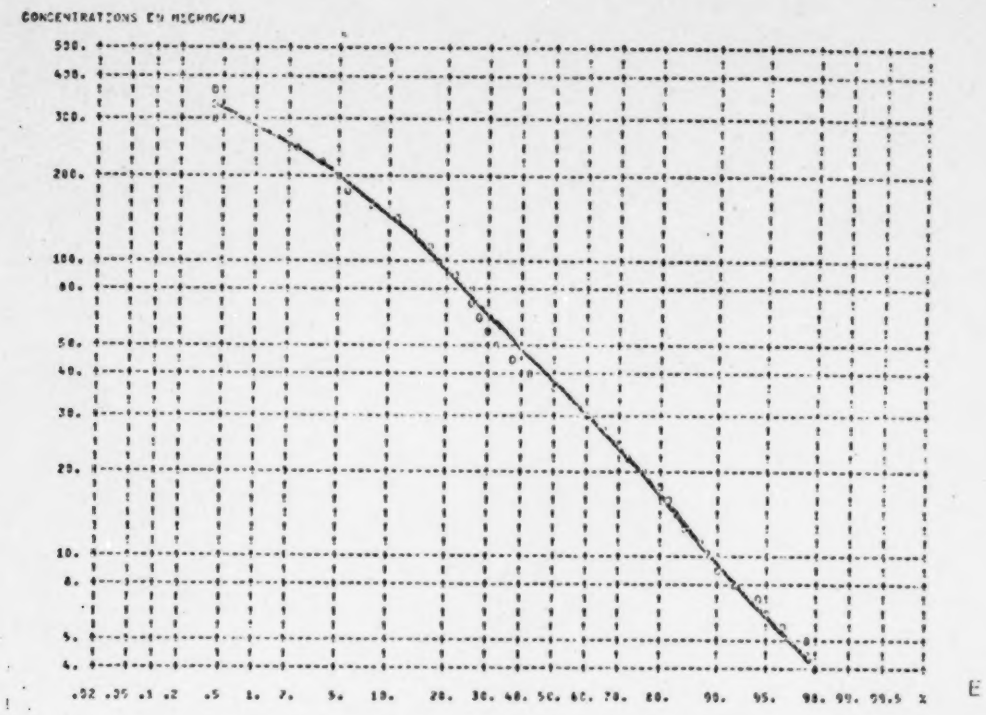


Figure 16

Frequency distribution of short term concentrations, Point E

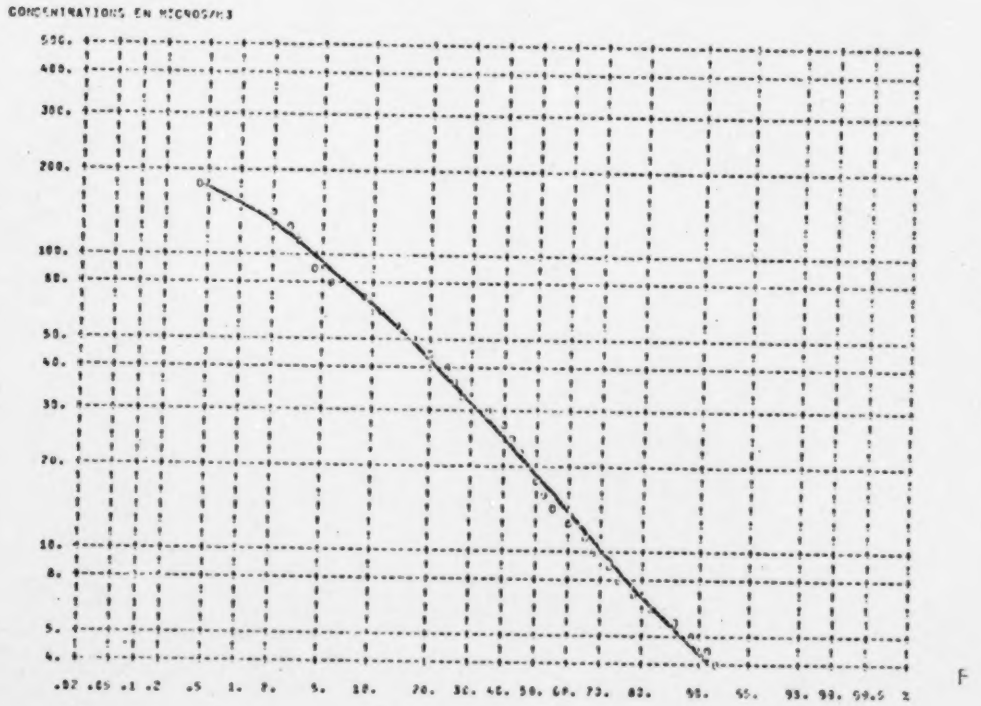


Figure 17

Frequency distribution of short term concentrations, Point F

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Berger, Demuth, Jacquardt, Schayes;
Belgium (LPADM)

décembre 1976.

Université Catholique de Louvain
Institut d'Astronomie et de Géophysique
Georges Lemaître

Contribution N° 16

Practical demonstration of Multiple Source Urban Air Quality Modeling (Gaussian Plume)

Preliminary results of applying the LMAQM model to the standard data base of Frankfurt/Main.

A.BERGER , Cl. DEMUTH , Y. JACQUART , G. SCHAYES .

Technical Document 1/1976 M.P.1.5
NATO/CCMS AIR POLLUTION STUDY
MODELING PANEL

SUMMARY

The Long Period Averaging Dispersion Model (bi-gaussian version), which is described in this report, has been applied to the NATO/CCMS Standard data base for the Frankfurt region(submitted by Federal Republic of Germany). The annual averaged concentration has been mapped for the whole region, a distinction being made between the contributions due to point and areasources. The frequency distribution is also given for six specified receptor locations. A table summarizes the " gaussian plume " results already obtained by other participators in the Frankfurt City Test of the NATO/CCMS Air Pollution Pilot Study, Air Pollution Modelling.

INTRODUCTION

The model used in this report is the bi-gaussian version of a more general model LPADM which is developped at the Mathematical Modeling Unit (AL/4.1) of the belgian Environment National Program R-D. In this experiment, the theoritical background is based upon the well-know gaussian solution of the diffusion equation (Berger, 1969).

This particular application to the Frankfurt region must be considered as preliminary as only a limited number of informations was available :any information which is requested by the model and which was not available, has been replaced by an estimated value. As no vertical profile of the planetary boundary layer was available and as the topography in the Frankfurt region is not negligible (LPADM is a model for flat terrain), the results presented in this paper have to be considered as a theoretical exercice. This exercice must only allow comparison between the response of several different gaussian plume models, all using a common data base where only a fixed limited number of meteorological data is available.

This model has been run before receiving any information about immission in the Frankfurt region over the analysed period. Thus the model has not yet been "calibrated", i.e. no ajustment of the sensitive parameters of the model has been performed.

LPADM (bi-gaussian version) as applied to the FRANKFURT-CITY TEST

NAME : LONG PERIOD AVERAGE DISPERSION MODEL (LPADM)

TYPE : Analytical solution of the stationary diffusion equation where K_y and K_z are function of the downwind distance.

ABSTRACT :

1. The LPADM computes ground level concentration for one (or many) pollutant(s) released from point and area sources. The diffusion formula is an exact solution of

$$U \frac{\delta \chi}{\delta x} = K_y(x) \frac{\delta^2 \chi}{\delta y^2} + K_z(x) \frac{\delta^2 \chi}{\delta z^2}$$

As that solution has a form similar to the usual Gaussian Plume formula, it is classed as a bi-Gaussian model. The algorithm of the program is based upon the CDM (Busse and Zimmerman, 1973)

2. Characteristics of the model .

- 6 stability classes as defined by Pasquill-Gifford
- 16 wind direction classes
- 6 wind speed classes
- temperature of the ambiant air is fixed to 9.7°C for the whole year
- plume rise from Briggs
- simulation of area sources
- the only diffusion parameter used is $\sigma_z = ax^b$
- mixing height depends upon the stability class and upon the observed mixing height during the afternoon and at night

- power law for the vertical wind profile
- half-life of SO_2 : 3 hours for each stability class
- flat terrain
- no dry deposition
- calm wind situations are eliminated
- size of the computation grid : 1 km x 1 km

3. Characteristics of the input grid and of the emission .

- geographic location is established with the aid of a Gauss-Krüger network.
- dimension of the region in W-E direction : $9 \text{ km} \leq x \leq 47 \text{ km}$
  in N-S direction : $17 \text{ km} \leq y \leq 43 \text{ km}$
- size of the area source is 500 m x 500 m
- 679 point sources and 1457 area sources are considered
- annual average of SO_2 emission per hour for each area source is obtained by multiplying the emission given in the data base by the factor 1560/8760.

4. Results :

From the joint frequency distribution F (is, id , iw) of the different meteorological situations defined from the wind direction (id) , wind speed (iw) and stability class (is) and three-hourly recorded over one year (1 August 1971- 31 July 1972) , the model provides a map of the mean concentration over the area defined by $14 \text{ km} \leq x \leq 33 \text{ km}$ and $24 \text{ km} \leq y \leq 34 \text{km}$ and the frequency distribution of concentration at six receptor points.

BASIC EQUATIONS

1. Point sources.

The ground level concentration over a flat terrain is estimated (for N point sources ip) from :

$$\chi = \sum_{ip=1}^{N} \sum_{is,id,iw} Y(ip,is,id,iw)\ Z(ip,is,id,iw) \quad \text{where} \tag{1}$$

$$Y = \frac{16}{2\pi}\ F(is,id,iw)\ \frac{1}{x_{ip}} \tag{2}$$

$$Z = \frac{2Q_{ip}}{U(is,iw)\sqrt{2\pi}\ \sigma_z(x,is)} \left[\exp\left(-\frac{H^2}{2\sigma_z^2(x,is)}\right) + \sum_{n=1}^{\infty} \exp\left[-\frac{(H-2nL)^2}{2\sigma_z^2(x,is)}\right] + \sum_{n=1}^{\infty} \exp\left[-\frac{(H+2nL)}{2\sigma_z^2(x,is)}\right]\right] \tag{3a}$$

$$Z = \frac{Q_{ip}}{U(is,iw)\ L(is)} \left[1 + 2\sum_{n=1}^{\infty} \cos\frac{n\pi H}{L} \exp\left[-\frac{n^2\pi^2\sigma_z^2}{2L^2}\right]\right] \tag{3b}$$

Y = is an average of the crosswind gaussian dispersion for long period of time.

is = stability class id = wind direction class iw = wind speed class.

x_{ip}, y_{ip} : downwind and crosswind distance from the source ip to the receptor.

χ : average concentration of pollutant j at the point (x,y) (gr/sec).

Q_{ip} : emission rate of pollutant j (gr/sec).

L(is) : mixing height as a function of the stability class (is), (m).

H(is,iw) : effective stack height: $H = \Delta h + h_g$ (m)

Δh : plume rise

h_g : geometrical stack height

U(is,iw) : mean horizontal wind speed at the top of the stack.

$\sigma_z(x,is)$: vertical diffusion parameters.

F(is,id,iw): joint frequency distribution of wind direction id, wind speed iw, and stability class is.

Z is determined from

(3a) without reflection terms (no summation) if

$$0 < \frac{\sigma_z}{L} < 0.4 \left(1 - \frac{H}{2L}\right)$$

(3a) with n = 2 if $0.4 \left(1 - \frac{H}{2L}\right) \leq \frac{\sigma_z}{L} < 0.8$

(3b) with n = 1 if $0.8 \leq \frac{\sigma_z}{L} < 1.6$

(3b) without reflection terms (no summation) if $1.6 \leq \frac{\sigma_z}{L}$

2. Area sources.

Numerical integration of the point sources formula.

3. Plume rise formula.

a. Point sources :

1) Briggs : unstable conditions (A,B,C,D) :

$$\Delta h.U = \begin{cases} 1.6\ F^{1/3}(3.5X^{*})^{2/3} & \text{if } x > 3.5X^{*} \\ 1.6\ F^{1/3}\ x^{2/3} & \text{if } x \leqslant 3.5X^{*} \end{cases} \quad \text{where} \quad X^{*} = \begin{cases} 14\ F^{5/8} & \text{if } F \leqslant 55 \\ 34\ F^{2/5} & \text{if } F > 55 \end{cases}$$

stable conditions (E,F) :

$$\begin{cases} \Delta h = \dfrac{1.6}{U}\ F^{1/3}\ x^{2/3} \\ \Delta h_{max} = 2.4\ [F\ T_a/(g\ US)]^{1/3} \end{cases} \quad \text{where} \quad \begin{cases} S = 0.02 \text{ for stability class E} \\ S = 0.035 \text{ for stability class F} \end{cases}$$

the buoyancy flux being given by :

$$F = g v_s \frac{d^2{}_s}{4} \frac{\Delta T}{T_s}$$

b. Area sources : the effective height is equal to the geometrical height of the area sources.

INPUT

1. Meteorological parameters :

- the three parameters joint frequency distribution F(is,id,iw). F has been determined from the three-hourly meteorological data recorded from 1 Aug. 1971 to 31 July 1972. The magnetic tape sent by Dr. B. Gutsche on 22 July 1976 has been used as input of a program FIJK which creates the joint frequency distribution.
- mixing height in the afternoon (HT) and at night (HMIN).
- mean wind speed per wind speed class fixed in Table 4.
- height at the anemometer level (10m).

a. Stability class :

the Pasquill-Gifford (A-G) stability classes are used (Busse and Zimmerman, 1973) but limited to E : only 6 stability classes, as defined by Turner (1970), are considered (Table 3).

b. Diffusion parameters : $\sigma_z = a\,x^b$

a,b - after Pasquill-Gifford (Busse and Zimmerman, 1971) for $h_g < 50m$

- after Singer-Smith (Niewstadt and van Dop , 1975) for $h_g \geq 50m$

(Tables 1 and 2).

c. Mixing height : $L = L(is) = f(HT, HMIN)$ (Table 3)

In a first run, HT = HMIN = 2km.

d. Horizontal wind speed : 6 wind speed classes.

For each class the boundaries and the mean wind speed is given in Table 4. This mean value is not the observed value over the given period but is fixed as in CDM.

e. Horizontal wind direction :

16 sectors (22°5) for the wind rose, the first one being centered upon the North.

f. Vertical wind profile : power law

$$u(z) = u(z_o) \left(\frac{z}{z_o}\right)^m$$

m is a function of the stability class (Table 3)

$u(z_o)$: wind speed at the anemometer level.
is also a function of the wind speed class (Table 4).

g. Transport wind speed : at the geometrical stack height h_g : U (is,iw)

U is deduced from the power law wind profile.

2. Emission

a. point sources :

- 679 point sources are localised in a Gauss-Krüger network
- winter, summer and year SO_2-output are given in kg/hr

b. stack data :

- h_t : geodetical height (ground surface) at the stack location in meter
- h_g : geometrical stack height in meter
- v_s : speed of emission in m/sec^{-1}
- d_s : diameter at the stack opening in meter
- ΔT : $T_s - T_a$
- T_s : temperature of the gas at the stack opening in °C
- T_a : temperature of the ambient air : ground level value is used and taken as a constant (9.7°C) through all the year.

c. area source :

- inventory is specified in the Gauss-Krüger grid system.
- each unit area is 500 m x 500 m
- the grid point of the calculation grid (mesh size of 1 km x 1 km) are chosen so as the coïncide with some of the corners of these area sources (exactly 4 area sources are contained in one mesh of the calculation grid)
- for each residential unit area, the average geometrical height of the source (≤800 000 kcal/hr) and the emission output in

kg/heating hours are documented.
- the number of heating hours is 1560 over the whole period considered.

RESULTS

1. - Figures 1 to 3 give the isopleths of the annual averaged concentration due respectively to the point sources, area sources and all sources when the mixing height during the afternoon and at night is a constant equal to 2 km. The coordinates of the S-W corner point of the mapped region are (14,24) and for the N-E corner (33,34). Iso-concentration lines are drawn each 10 µg SO_2/m^3.
   - Tables 5 to 7 give the concentration at grid points as mapped on figures 1 to 3.

2. - Annual mean SO_2 concentration at the 6 receptor points are given in table 8.
   - For each of the receptor points, the characteristics of the frequency distribution are given in table 9 : the 98th percentile, the geometrical mean, the standard deviation s_g, the slope of the regression line in a log-normal diagram given by $tg\ \theta = 1/\ln s_g$
   - Figures 4 to 9 give the frequency distribution at these 6 receptor points in a log-normal diagram (cumulative frequency in a standard deviations scale versus SO_2 concentration in a logarithmic scale).

3. Computations have been performed on an IBM 370/158. The CPU time required is for the point sources : 43^m and for the area sources : 38^m. Graphs have been made on a XYNETICS 1100, the CPU time to generate figure 1 is 15^s, figure 2 is 18^s, figure 3 is 18^s. Both IBM and XYNETICS are at the Computer Center of the Université Catholique de Louvain.

4. The same computations are now being performed for the winter and the summer seasons.

5. As the LPADM cannot solve calm wind problem, these situations have been taken out from the sample of data. They represent 208 cases out of the 2655 (7.8 %) going from 1 August 1971 to 31 July 1972. The results presented here are thus amount or mean computed over all the situations where a calm wind does not prevail.
Unfortunately, this will create a problem when comparing theoritical results and measured concentrations, using the frequency distributions. Indeed, as usually the sampling period of pollutants (integration over one day) is not equal to the interval over which meteorological parameters can be considered as a constant (1 or even 3 hours), calm wind situations can not be taken out from the frequency distribution of the observed concentrations.

SENSITIVITY

Sensitivity has been analysed for the only HMIN parameter. Computations have been performed only for stability class is=6 and wind speed classes iw=1 and 2,these meteorological situations being assumed to be the most pollutant as far as inversion level is considered (also frequencies for wind speed classes higher than 2 are negligible for is=6).
Maximum value of H/L and σ_z/L (3a and 3b) has then been determined for sources that can contribute significantly to the computed concentration at each of the 6 receptor points. From table 10, it is easy to verify that the influence of the inversion level become to be negligible as far as the following inequality is verified (3a):

$$0 < \sigma_z/L < 0.4 \ (1-H/2L)$$

i.e. as far as HMIN is higher than 200 m. Thus for inversion level at night lower than 200 m. ,the influence of the inversion level becomes to be significant as far as the source-to-receptor distance is smaller than a critical value (influence of Y in (2)).

Receptor	TURNER			IRWIN			NIEUWSTADT			BERGER			TEXAS AIR CON.		
	P	A	S	P	A	S	P	A	S	P	A	S	P	A	S
1	16	55	71	4	68	72	21	58	79	21	53	74	14	109	123
2	15	45	60	4	53	57	17	48	65	16	44	60	13	84	97
3	16	60	76	3	72	75	21	67	88	18	59	77	16	95	111
4	14	39	53	3	44	47	29	41	70	19	36	55	15	70	85
5	13	17	30	2	19	21	15	30	45	14	16	30	15	8	23
6	11	26	37	2	36	38	12	30	42	9	25	34	8	43	51

Comparison with other calculationsfrom preliminary results obtained by some participants at the Practical Demonstration for Frankfurt.(Nieuwstadt,1976)

P concentrations from point sources in $\mu g/m^3$
A concentrations from the area sources in $\mu g/m^3$
S total concentration in $\mu g/m^3$

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Table 1 Pasquill-Gifford coefficients for the diffusion parameters.

stability class		$x \leq 500$		$500 < x \leq 5000$		$5000 < x$	
		a	b	a	b	a	b
A		0.0383	1.2812	$0.2539\ 10^{-3}$	2.0886	$0.2539\ 10^{-3}$	2.0886
B		0.1393	0.9467	$0.4936\ 10^{-1}$	1.1137	$0.4936\ 10^{-1}$	1.1137
C		0.1120	0.9100	0.1014	0.9260	0.1154	0.9109
D	day	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642
	night	0.0818	0.8155	0.2527	0.6341	1.2969	0.4421
E		0.0545	0.8124	0.2017	0.6020	1.5763	0.3406

Table 2 Singer-Smith coefficients for the diffusion parameters.

stability class	a	b
A	0.411	0.907
B	0.411	0.907
C	0.326	0.859
D (<11 knots)	0.326	0.859
D (≥11 knots	0.223	0.776
E	0.062	0.709

Table 3 Vertical wind profile and mixing height.

stability class	is	exponent in the vertical wind profile : m	mixing height L
A	1	0.1	1.5 HT
B	2	0.15	HT
C	3	0.20	HT
D_{day}	4	0.25	HT
D_{night}	5	0.25	(HT + HMIN)/2
E, F, G	6	0.30	HMIN

Table 4 Wind speed classes.

boundaries (knots)	wind speed classes iw	$u(z_o)$ (m/sec)
0 - 3	1	1.5
4 - 6	2	2.46
7 - 10	3	4.47
11 - 16	4	6.93
17 - 21	5	9.61
> 21	6	12.52

(DM:BI-GAUSSIAN MODEL
(OGRAMS PER CUBIC METER) Berger ( )

MAXIMAL CONCENTRATION= 25.7

MINIMAL CONCENTRATION= 6.6

11	7.3	8.7	9.8	9.9	10.6	11.3	11.2	10.3	10.6	11.1	10.3	11.4	11.6	11.0	10.0	9.5	9.4	9.0	8.6	8.2
10	7.3	10.1	10.6	10.6	11.8	12.6	12.4	12.8	12.8	12.9	11.3	11.3	12.6	11.3	10.8	10.4	10.1	9.9	9.3	8.8
9	8.5	12.3	11.3	12.6	12.9	14.1	14.2	14.9	14.2	12.8	13.3	12.3	12.6	12.2	12.0	11.1	10.4	11.2	9.7	8.6
8	9.3	13.2	12.8	15.1	14.6	17.6	16.4	16.4	15.6	13.5	14.1	14.0	14.5	14.4	13.6	12.8	11.5	11.9	8.9	9.1
7	11.3	14.2	15.1	17.0	17.8	18.6	17.8	17.7	15.7	13.8	16.2	18.1	16.6	16.3	15.1	14.2	12.0	10.4	9.2	8.8
6	11.9	14.9	16.8	19.4	20.3	19.7	21.4	17.0	17.6	16.4	19.7	19.7	20.0	17.3	17.0	13.7	13.0	11.5	9.3	8.0
5	13.3	14.1	18.0	21.7	22.8	19.6	18.9	19.1	18.9	17.3	19.5	20.5	20.5	16.5	15.8	15.2	12.9	10.6	10.0	8.0
4	15.1	15.1	18.8	24.1	21.4	21.0	22.2	23.4	19.9	18.6	15.6	18.9	16.4	15.6	14.8	12.8	11.6	11.2	10.8	12.7
3	21.2	18.4	20.6	21.4	22.6	20.2	20.1	20.3	18.7	18.2	16.7	13.2	14.1	14.8	12.4	11.2	10.7	11.0	11.1	11.5
2	22.2	22.1	20.7	19.3	20.0	20.4	19.2	16.9	15.9	17.9	13.9	12.8	13.2	11.2	10.2	9.7	9.8	9.9	10.0	8.4
1	25.6	25.7	21.3	20.8	20.6	18.2	15.3	16.6	15.9	15.5	11.8	11.3	11.4	9.9	9.5	9.8	9.4	9.1	8.4	6.6
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Table 5 .
Annual averaged concentration in $\mu g/m^3$ due to emmissions from point sources, Frankfurt.

L( ):BI-GAUSSIAN MODEL
(M)ROGRAMS PER CUBIC METER) Berger ( )

MAXIMAL CONCENTRATION= 77.1

MINIMAL CONCENTRATION= 9.2

11	9.3	9.2	9.8	14.1	16.3	14.6	11.8	15.6	27.3	29.4	24.7	29.3	28.1	25.7	22.5	23.3	18.1	14.5	14.0	11.2
10	10.0	10.1	12.5	15.4	13.3	13.1	14.6	20.4	32.4	34.5	41.6	39.2	33.6	35.3	24.8	22.1	18.4	19.9	19.5	13.0
9	13.9	12.9	20.5	14.1	17.5	15.7	17.5	25.6	36.1	29.9	37.3	49.6	45.9	38.4	31.8	28.4	27.0	27.6	25.3	14.9
8	16.9	18.8	19.6	18.1	22.1	17.6	20.6	29.8	37.2	30.9	47.2	50.1	53.3	51.1	41.7	45.6	35.2	27.5	20.8	16.1
7	13.8	17.4	16.1	17.0	19.7	23.4	25.2	35.5	39.6	35.3	48.2	49.3	63.3	77.1	66.1	39.0	37.3	24.5	22.5	16.8
6	12.7	13.8	17.4	24.7	33.1	24.3	31.1	43.0	39.8	53.1	60.1	62.2	75.5	72.8	71.1	37.3	22.4	19.7	22.1	25.3
5	15.2	21.2	33.0	32.9	22.2	24.5	28.5	30.9	35.9	47.1	50.7	57.9	59.0	58.4	47.5	22.9	20.0	26.1	28.2	29.4
4	21.8	25.9	35.9	33.0	28.4	30.2	35.5	36.3	52.9	52.1	45.6	49.9	60.9	47.7	26.3	21.8	23.4	32.8	37.5	31.6
3	21.9	24.6	24.1	21.7	25.5	30.7	35.7	47.0	48.0	35.6	39.7	45.2	45.5	26.8	19.1	21.6	19.3	31.1	36.6	36.8
2	19.0	18.9	19.1	18.4	26.4	31.4	34.7	38.0	31.9	40.8	43.1	32.2	25.7	19.3	19.0	16.3	18.9	27.5	23.7	24.5
1	18.8	15.8	16.8	17.8	18.4	22.5	23.4	24.4	23.7	28.4	26.4	19.0	17.8	14.0	14.0	14.0	15.5	16.5	16.7	12.5
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Table 6 .

Annual averaged concentration in $\mu g/m^3$ due to emmissions from area sources, Frankfurt.

LP/ MIBI-GAUSSIAN MODEL
(MICROGRAMS PER CUBIC METER)

MAXIMAL CONCENTRATION= 95.5

MINIMAL CONCENTRATION= 16.6

11	16.6	17.9	19.5	24.0	26.9	25.9	23.0	25.9	38.0	40.5	35.0	40.7	39.7	36.7	32.4	32.9	27.6	23.5	22.6	19.4
10	17.3	20.2	23.1	26.0	25.2	25.7	27.0	33.2	45.2	47.4	52.8	50.5	46.2	46.5	35.7	32.5	28.5	29.7	28.9	21.8
9	22.4	25.2	31.8	26.7	30.4	25.8	31.7	40.5	50.3	42.7	50.7	61.8	58.5	50.6	43.8	39.5	37.4	38.7	34.9	23.4
8	26.3	32.0	32.4	33.2	36.8	35.2	37.0	46.2	52.8	44.4	61.3	64.1	67.8	65.5	55.2	58.4	46.7	39.4	29.7	25.2
7	25.1	31.6	31.1	34.1	37.5	42.0	43.0	53.2	55.3	49.0	64.3	67.4	79.9	93.4	81.2	52.2	49.4	34.9	31.7	25.6
6	24.6	28.6	34.2	44.2	53.4	44.1	52.5	60.0	57.4	69.4	79.9	81.9	95.5	90.1	83.1	51.0	35.4	31.2	31.5	33.3
5	29.5	35.3	51.0	54.6	45.0	44.2	47.4	50.0	54.8	64.3	70.2	78.4	79.5	74.9	63.4	38.1	32.9	36.8	38.2	34.5
4	36.9	41.0	54.7	57.1	49.8	51.2	57.7	59.8	72.8	70.6	61.2	68.8	77.3	63.4	41.0	34.6	35.0	43.9	48.4	44.3
3	43.1	43.1	44.7	43.1	48.1	50.9	55.8	67.3	66.6	53.8	56.4	58.5	59.6	41.6	31.5	32.0	30.1	42.1	47.6	48.3
2	41.2	41.0	39.8	37.8	46.3	51.8	53.9	54.9	47.8	58.7	57.0	45.0	39.0	30.5	29.2	25.9	28.6	37.3	33.6	32.9
1	44.4	41.6	38.1	38.6	39.1	40.7	38.7	41.0	39.6	43.9	38.2	30.3	29.2	23.9	23.5	23.8	25.0	25.6	25.1	19.1
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Table 7 .

Annual averaged concentration in $\mu g/m^3$ due to emmissions from all sources, Frankfurt.

Berger

Table 8. Mean annual concentration at 6 receptor points in $\mu g\ SO_2/m^3$.

	COORDINATES OF RECEPTOR POINTS (km)		CONCENTRATION ($\mu g/m^3$) HT=2km HMIN = 2km		
	x	y	POINT SOURCE	AREA SOURCES	TOTAL
1	22.29	26.53	21	53	74
2	28.25	28.15	16	44	60
3	24.76	28.98	18	59	77
4	16.00	27.00	19	36	55
5	19.00	32.00	14	16	30
6	34.00	27.00	9	25	34

Berger

Table 9. Characteristics of the Frequency Distribution at six receptor points.

N°	RECEPTOR POINTS (km) x	y	GEOMETRICAL MEAN	98th PERCENTILE	STANDARD GEOMETRIC DEVIATION	SLOPE θ
1	22.29	26.53	57.91	274.77	2.1397	52.74
2	28.25	28.15	46.76	221.73	2.1390	52.75
3	24.76	28.98	63.07	276.50	2.0587	55.17
4	16.00	27.00	33.97	304.14	2.9179	43.04
5	19.00	32.00	17.40	194.58	3.2524	41.29
6	34.00	27.00	27.07	128.41	2.1394	52.75

Table 10.

N°	COORDINATES OF RECEPTOR POINTS (km)		is = 6 iw = 1,2 HMIN = 500m		
			NUMBER OF POINT SOURCES	$(H/L)_{max}$	$(\sigma_z/L)_{max}$
	x	y			
1	22.29	26.53	23	0.17	0.11
2	28.25	28.15	41	0.23	0.12
3	24.76	28.98	30	0.18 (0.41*)	0.11 (0.05*)
4	16.00	27.00	22	0.14	0.12
5	19.00	32.00	8	0.14	0.08
6	34.00	27.00	13	0.15 (0.30**)	0.12 (0.04**)

* for the source coordinates : x = 23,05 km , y = 33,45 km

** for the source coordinates : x = 32,29 km , y = 29,87 km

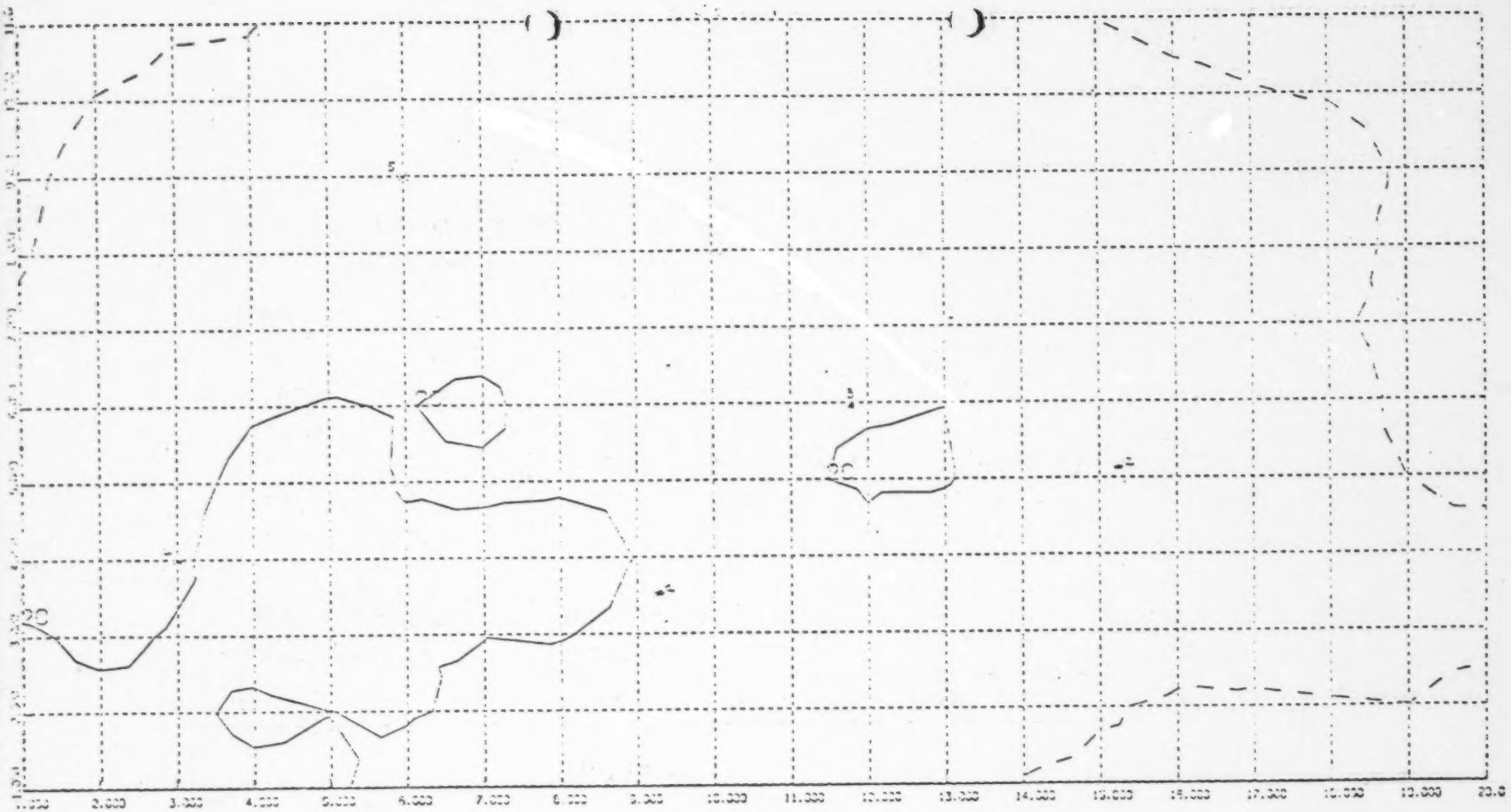

Fig. 1 : Annual averaged concentration in $\mu g/m^3$ due to emissions from point sources for Frankfurt.

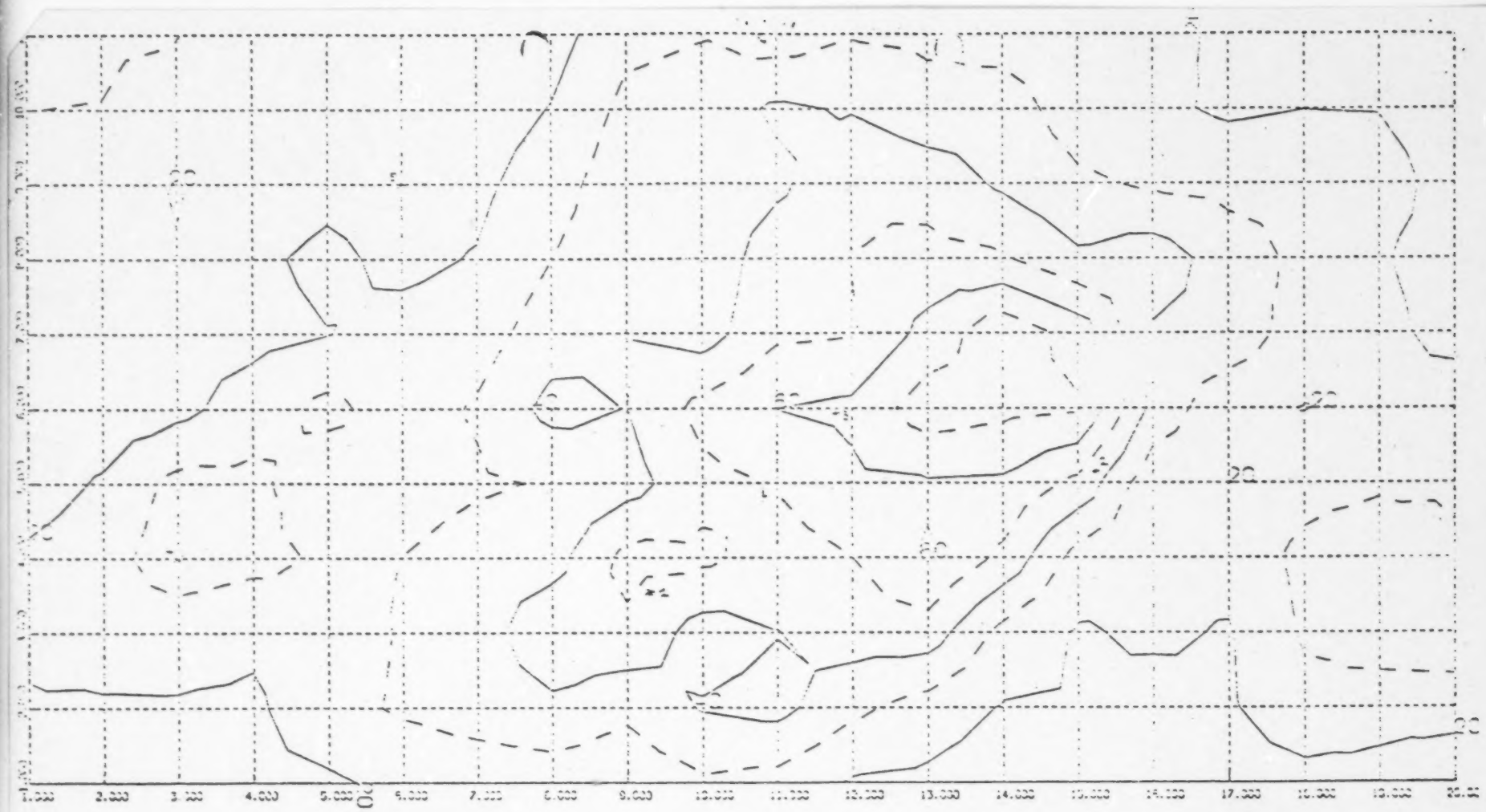

Fig. 2 : Annual averaged concentration in $\mu g/m^3$ due to emissions from area sources for Frankfurt.

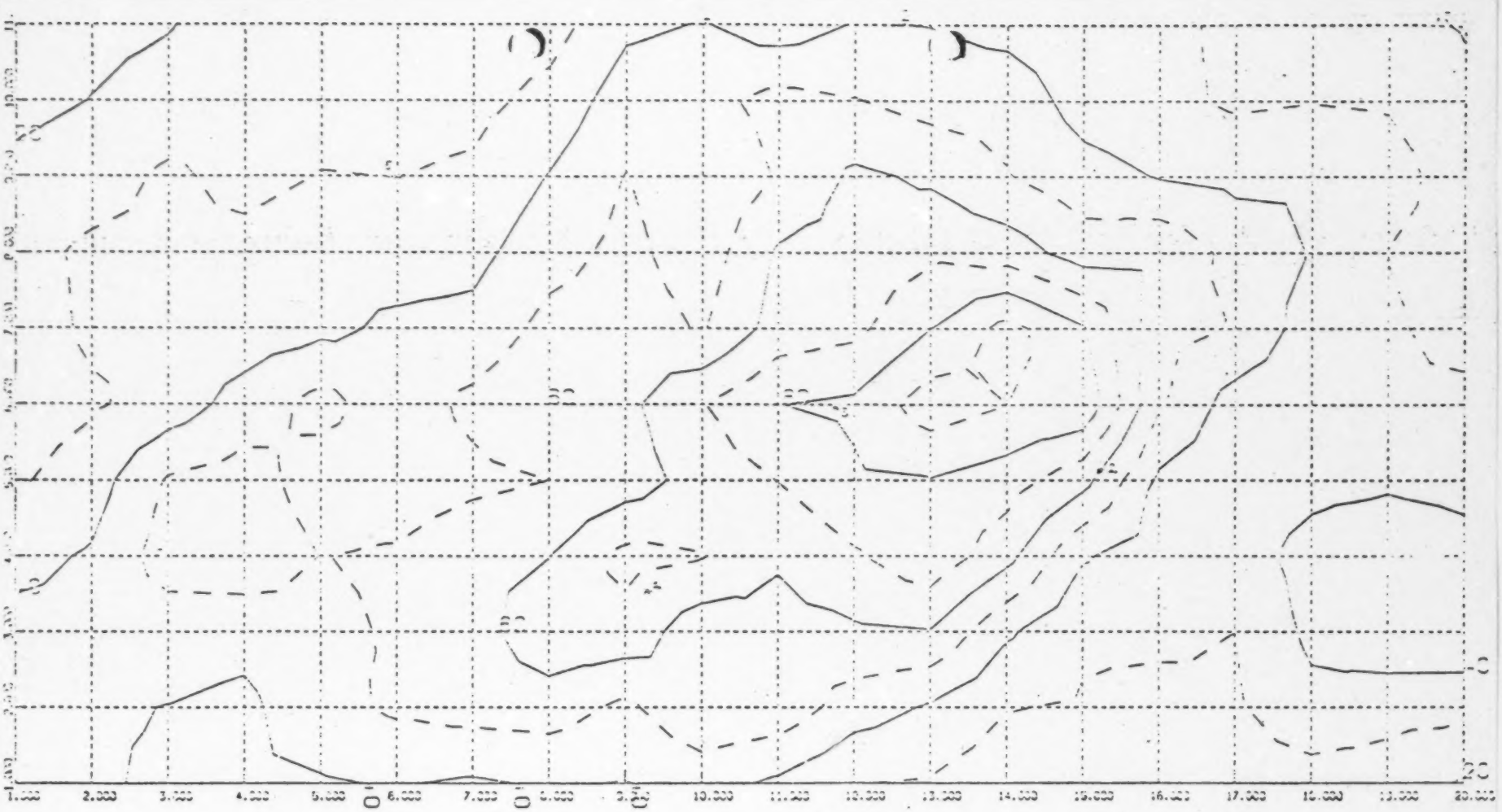

Fig. 3 : Annual averaged concentration in $\mu g/m^3$ due to emissions from all sources for Frankfurt.

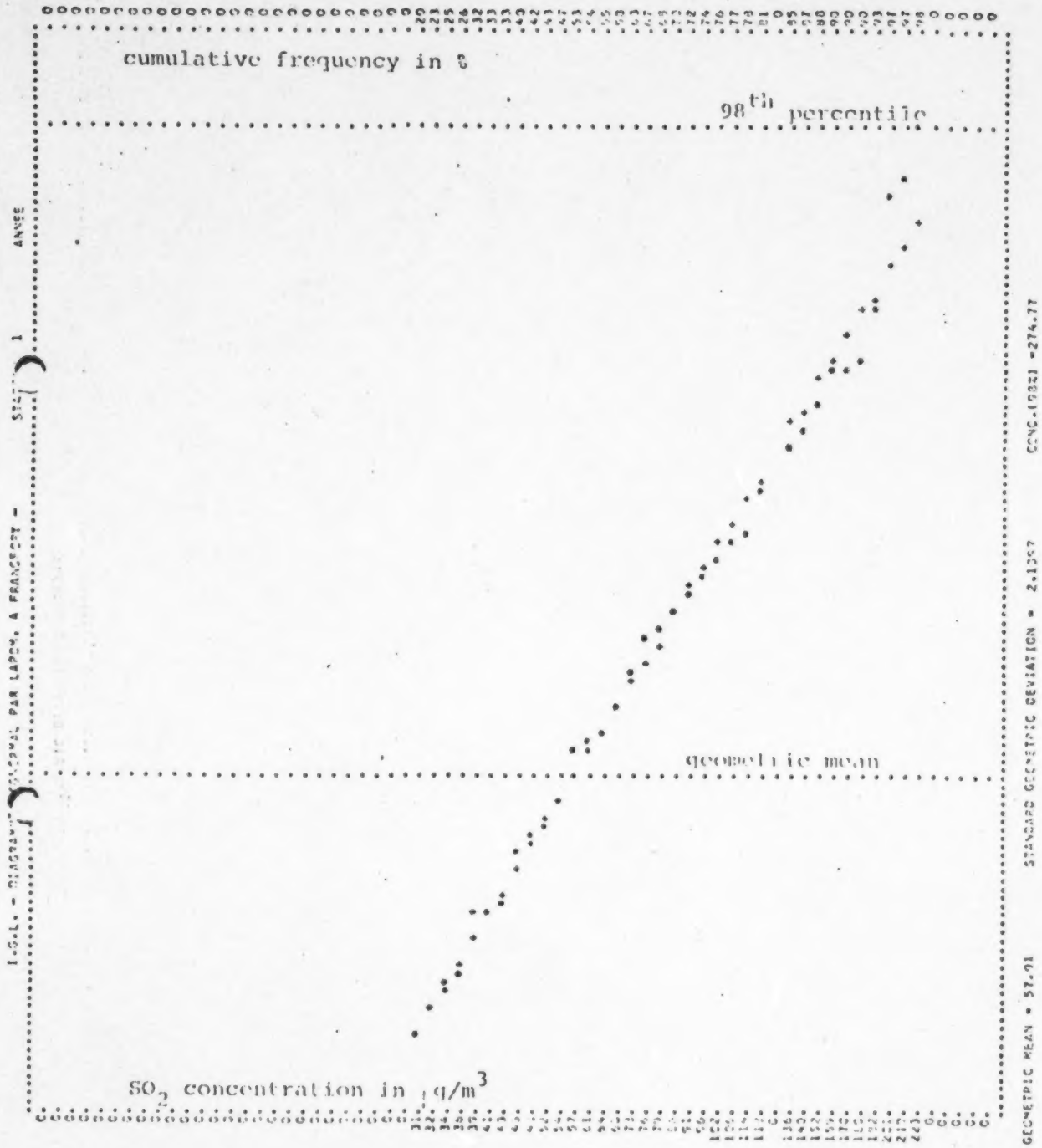

Fig. 4.

abscissa gives the SO_2 concentration (logarithmic scale)

ordinate gives the cumulative frequency

* computed concentration

\+ regression line

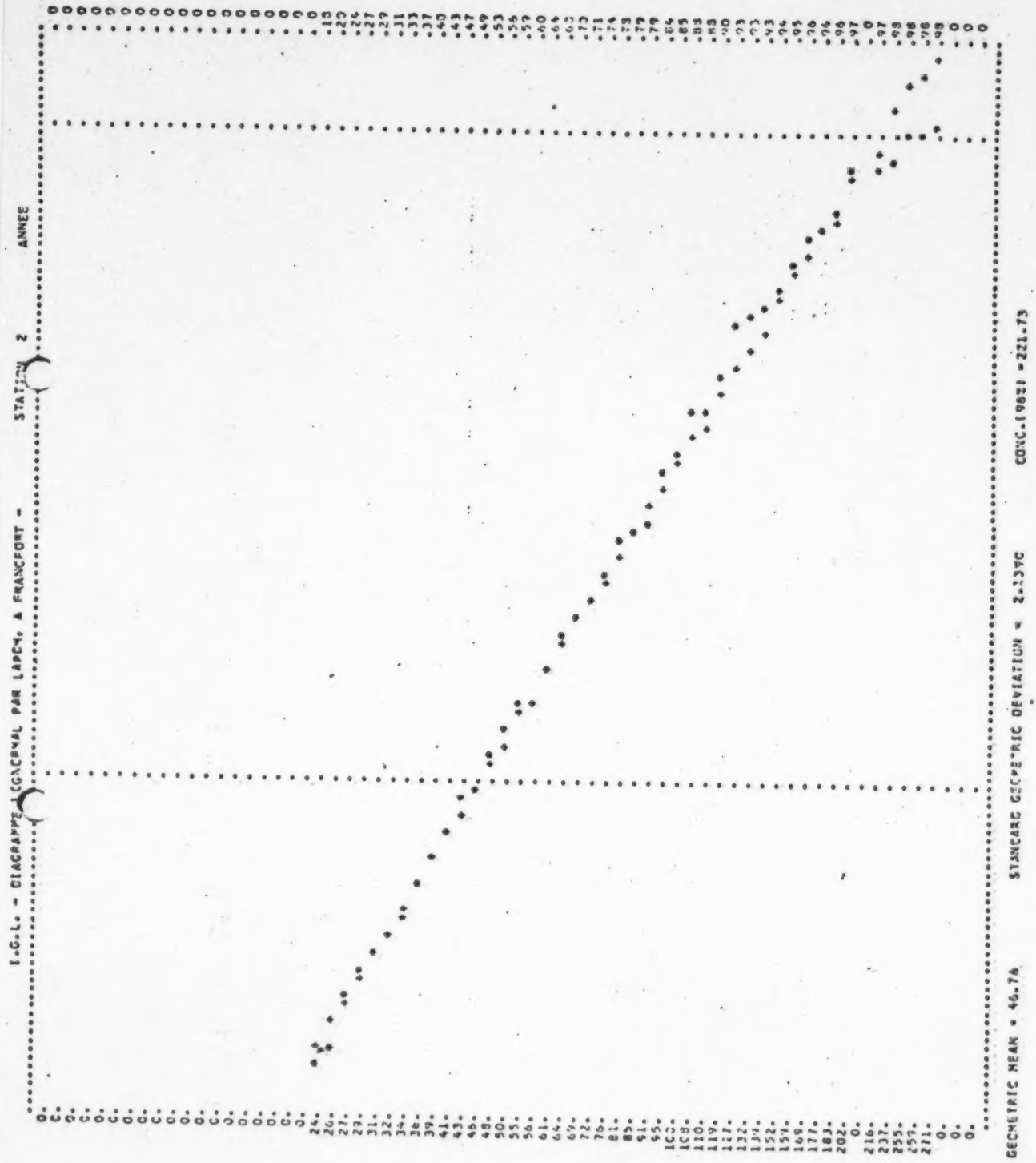
I.G.L. - DIAGRAMME LOGNORMAL PAR LAPON, A FRANCFORT - STATION 2 ANNEE
GEOMETRIC MEAN = 46.76
STANDARD GEOMETRIC DEVIATION = 2.1390
CONC.(98%) =221.73

Fig. 5.

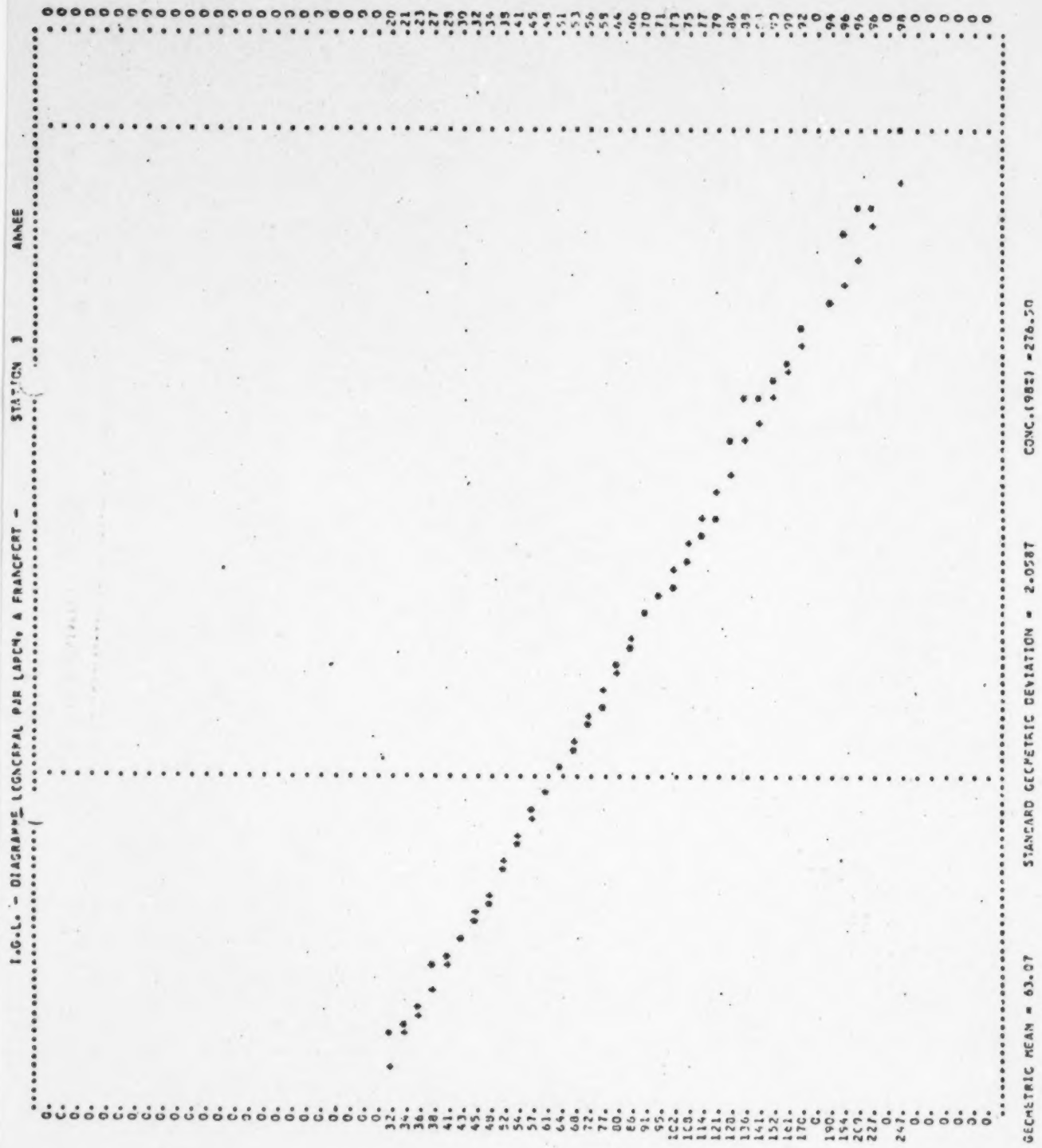
I.G.L. - DIAGRAMME LOGNORMAL PAR LAPCM, A FRANCFORT - STATION 3 ANNEE
GEOMETRIC MEAN = 63.07
STANDARD GEOMETRIC DEVIATION = 2.0587
CONC.(98%) =276.50

Fig. 6.

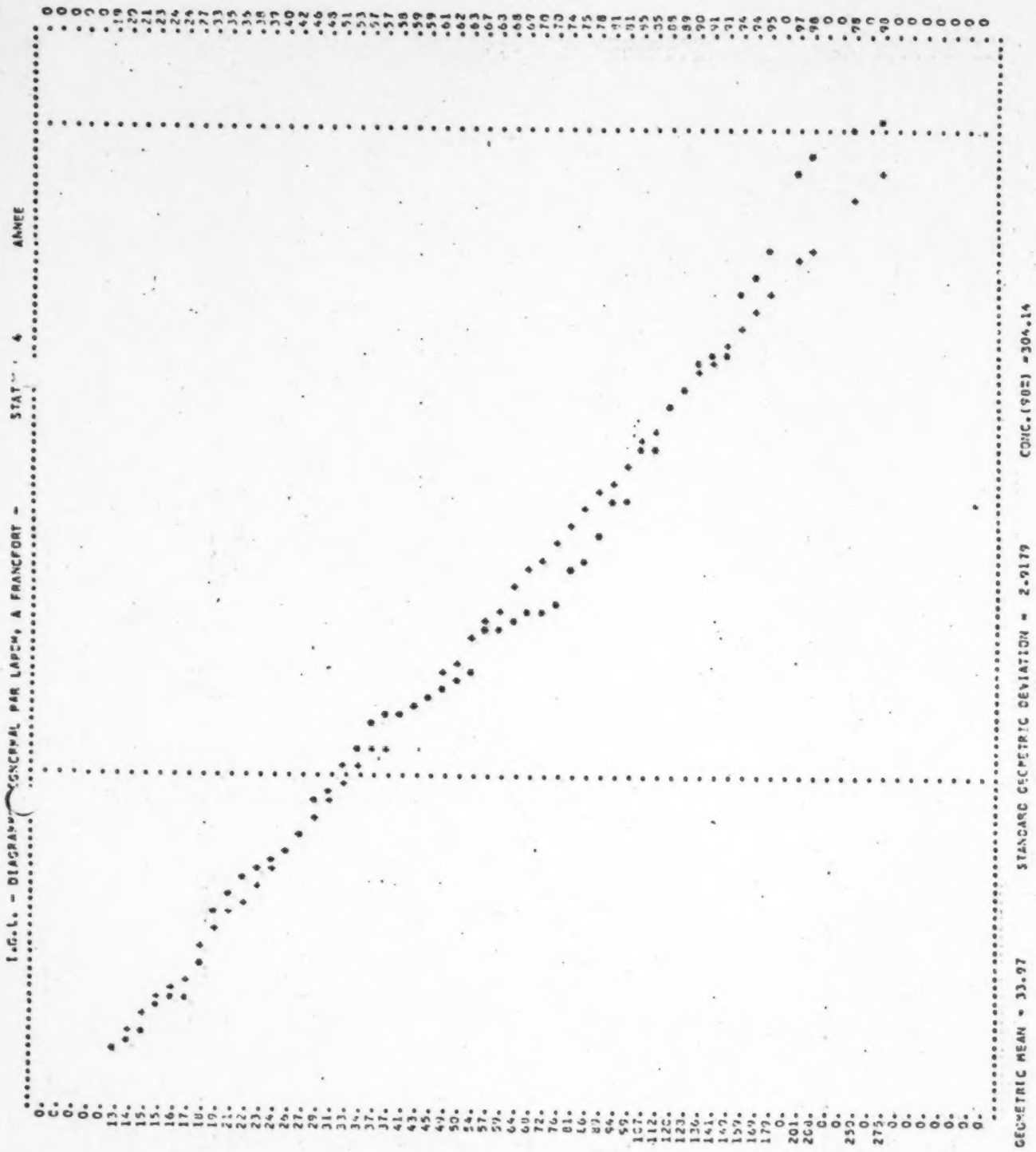
ANNEE
STAT 4
GEOMETRIC MEAN = 33.97
STANDARD GEOMETRIC DEVIATION = 2.9179
CONC.(90%) =304.14

Fig. 7.

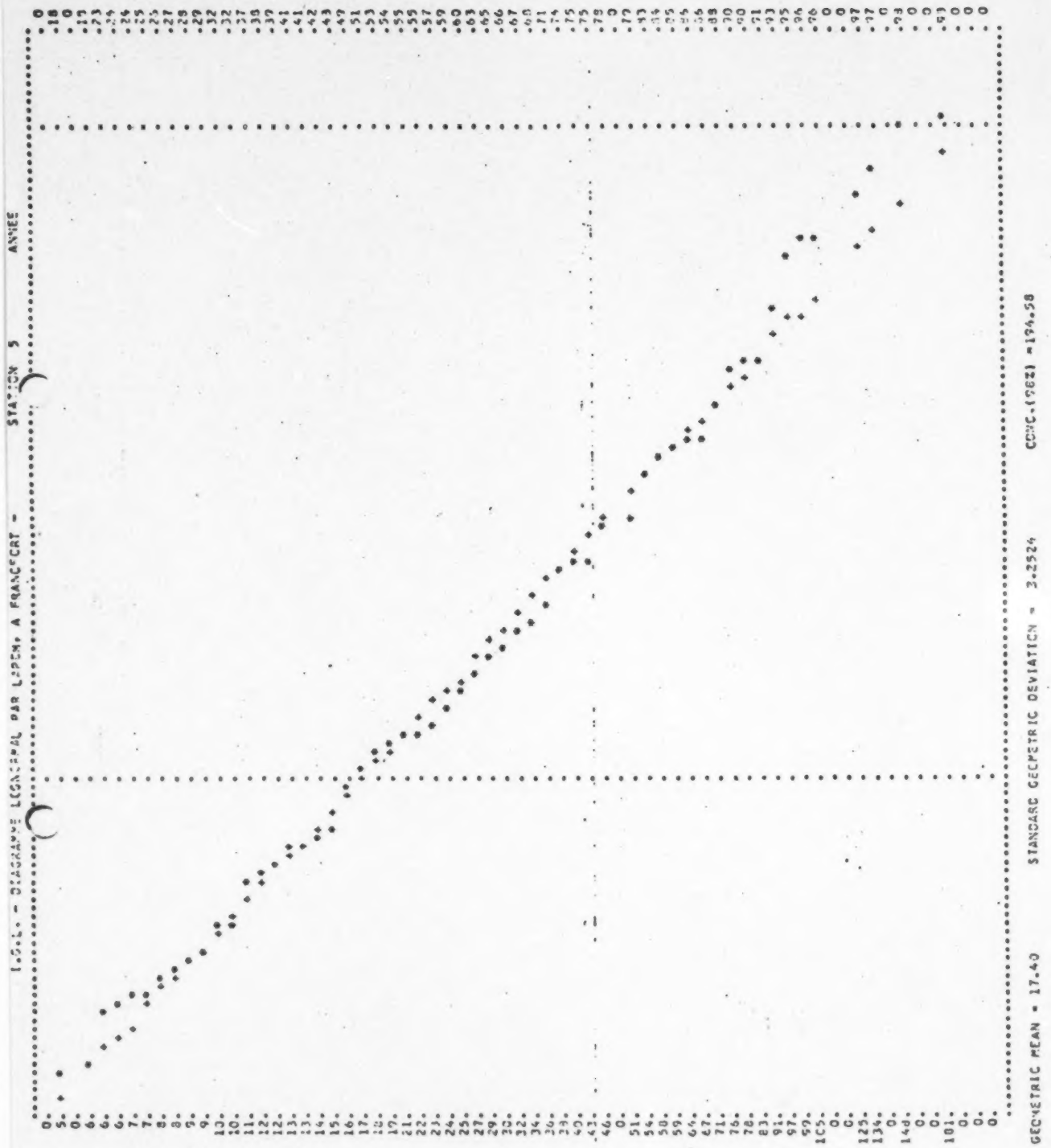
STATION 5
ANNEE
GEOMETRIC MEAN - 17.40
STANDARD GEOMETRIC DEVIATION - 3.2524
CDMC.(1962) =194.58

Fig. 8.

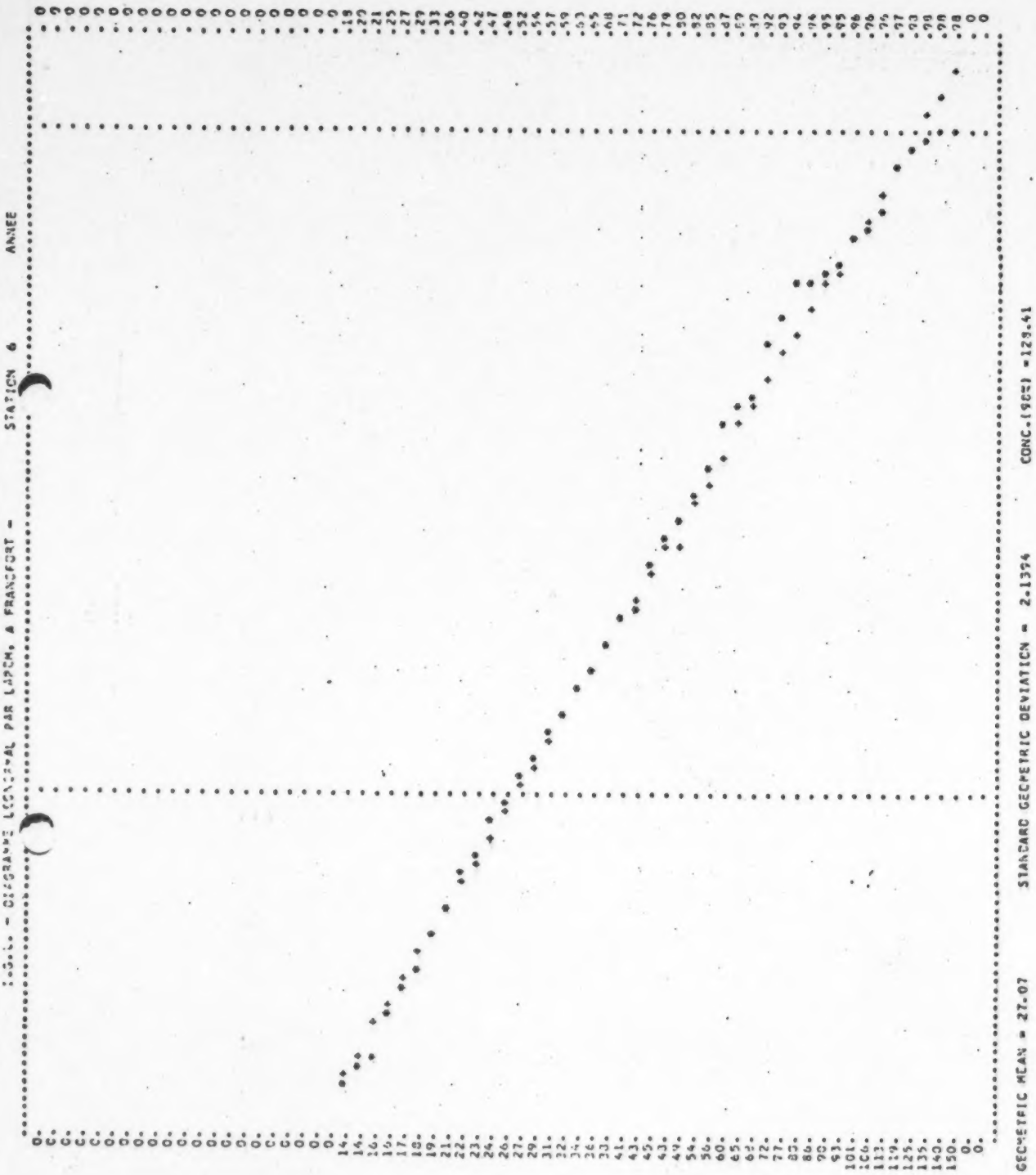
STATION 6
ANNEE
GEOMETRIC MEAN = 27.07
STANDARD GEOMETRIC DEVIATION = 2.1394
CONC.(90%) =128.41

Fig. 9.

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Kretzschmar, De Baere, Mertens,
Vanderven; Belgium
(IFDM)

Application of the IFDM on the NATO common data base for the frankfurt area

J.G. Kretzschmar
G. De Baere
J. Vandervee
I. Mertens

S.C.K./C.E.N., MOL, BELGIUM

December 1976.

1. Introduction

The multiple source Gaussian type disperion model IFDM (Immission Frequency Distribution Model) has been applied to the standard data base for SO_2 of the Frankfurt region in order to obtain yearly averages for SO_2 in the 187 (17x11) receptor points of a regular network with a grid size of 1km. The area chosen for the calculations is defined by the following Gauss-Krüger coordinates :

$$3468 \leq x \leq 3484$$
$$5549 \leq y \leq 5559$$

The following remarks should be made regarding the use of the data base. The area sources were transformed into point sources since the available data were not suitable for application of the normal procedure used for area sources in IFDM. The source height, emission rate and location of these "point sources" were calculated for 1 km^2 zones on the base of the data originally given for 500m x 500m zones. The annual average emissions were obtained by multiplying the emissions, given in the data base, by a factor 1560/8784. This is the ratio of the number of yearly heating hours to the total number of hours in the period (8784 = 366 x 24). Sources with an emission less than 1,5 kg/h are neglected. Area sources at a distance of more than 2 km from the boundaries of the grid are not taken into account. Sources at a distance between 1 and 2 km of the boundaries are accepted if their annual average emission is larger than 3kg/h. The number of fictitious point sources that has been taken into account is 145. Fig. 1 represents the location of these sources.

.../...

Within the specified area all (real) industrial point sources with an annual average emission of more than 2kg/h are included. Outside the area only the most important sources are taken into account. The total number of point sources included in the program is 55 and Fig. 2 represents the location of these sources.

The meteorological data are summarised in the frequency distribution in Table 1. Sixteen 22,5° wind sectors, six wind speed classes (0 - 1,5; 2-3; 3,5-5; 5,5-8; 8,5-10,5; > 10,5 m/s) and five stability classes (Pasquill-Gifford classes A, B, C, D, E+F) were used.

The calculations were performed on the IBM 370/135 - computer of the S.C.K. - C.E.N. in Mol.

2. Description of the model.

A brief description of the FDM is given in the Appendix For the present study the ollowing changes were introduced.

2.1. Stability classes.

For the calculations with the data base for the Frankfurt area the Pasquill - Gifford stability classes are chosen. The corresponding σ_y and σ_z are given by :

$$\sigma_y(x) = Ax^a + \alpha$$
$$\sigma_z(x) = Bx^b + \beta$$

Table 2 summarises the numerical values of the different factors as a function of the stability classes. For the practical calculations the σ_y and σ_z values for the class E were used for E as well as for F.

.../...

Table 2 : Pasquill-Gifford stability classes and corresponding dispersion parameters.

Stability classes	A	a	α	B	b	β	Restrictions
A	0,527	0,865	0	0,006008	1,5548	6,2686	100m<x<400m
				0,0000938	2,2217	16,3731	400m<x<1000m
				0,000240	2,094	-9,6	1000m<x<3000m
B	0,371	0,866	0	0,0371	0,1530	3,1914	100m<x<1000m
				0,0540	1,0997	2,5397	1000m< <20000m
C	0,209	0,8[illegible]7	0	0,0992	0,9289	0,2444	100m<x<1000m
				0,0991	0,9255	1,7383	1000m<x<20000m
D	0,128	0,9[illegible]5	0	0,2066	0,7338	-1,3659	100m<x<1000m
				0,9248	0,5474	-9,0641	1000m<x<20000m
E	0,098	0,902	0	0,1975	0,6865	-1,1644	100m<x<1000m
				2,3441	0,4026	-16,3186	1000m<x<20000m
F	0,065	0,902	0	0,09842	0,7210	-0,3231	100m<x<1000m
				6,5266	0,2693	-25,1583	1000m<x<20000m

.../...

2.2. The distribution function of wind direction classes, stability classes and wind speed classes.

IFDM needs hourly meteorological data in order to obtain cumulative frequency distributions in the grid points. For the present study some changes were introduced in order to obtain yearly averages based on a joint frequency distribution of the meteorological situations as only this information was available.
The actual data used are summarised in Table 1.

2.3. Wind profile.

$$u(z) = u(z_0) \left(\frac{z}{z_0}\right)^m$$ with z_0 as reference height (10 m e.g.)

The exponent m is a function of the stability class.
The values used for the calculation are as follows :

stability class	m
A	0,10
B	0,15
C	0,20
D	0,25
E,F	0,25

2.4. Mixing height.

No mixing height has been taken into account.

.../...

3. Results.

Figure gives the annual averages in the different grid points. For the six specific receptor points the following results were obtained :

Receptor	coordinates (x,y)	SO_2 concentration
1	73,29 - 51,53	97 $\mu g/m^3$
2	74,25 - 53,15	78 $\mu g/m^3$
3	75,76 - 53,88	122 $\mu g/m^3$
4	67,00 - 52,00	70 $\mu g/m^3$
5	70,00 - 57,00	40 $\mu g/m^3$
6	85,00 - 52,00	52 $\mu g/m^3$

TABLE 1 : METEOROLOGICAL JOINT FREQUENCY FUNCTION *

STABILITY CLASS	WIND SPEED CLASS	RELATIVE FREQUENCIES OF OCCURRENCE FOR WIND SECTORS 1-16															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1	.00000	.00000	.00000	.00322	.00000	.00034	.00081	.00189	.00041	.00001	.00000	.00000	.00000	.00000	.00000	.00002
A	2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00027	.00000
A	3	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
A	4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
A	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
A	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
B	1	.00269	.00383	.00497	.00357	.00171	.00114	.00067	.00028	.00284	.00387	.00277	.00275	.00076	.00015	.00049	.00050
B	2	.00179	.00281	.00324	.00144	.00142	.00074	.00047	.00000	.00153	.00410	.00471	.00135	.00023	.00044	.00014	.00010
B	3	.00099	.00140	.00152	.00075	.00017	.00023	.00002	.00014	.00060	.00219	.00252	.00083	.00007	.00010	.00010	.00010
B	4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
B	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
B	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
C	1	.00231	.00445	.00643	.00528	.00487	.00265	.00152	.00032	.00330	.00407	.00406	.00239	.00117	.00094	.00071	.00094
C	2	.00154	.00523	.00578	.00275	.00137	.00145	.00100	.00070	.00224	.00554	.00376	.00132	.00053	.00055	.00036	.00023
C	3	.00151	.00632	.00724	.00247	.00247	.00069	.00047	.00053	.00232	.00415	.00413	.00367	.00254	.00178	.00132	.00130
C	4	.00009	.00065	.00010	.00052	.00034	.00000	.00000	.00000	.00018	.00047	.00095	.00100	.00023	.00024	.00010	.00000
C	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00012	.00056	.00000	.00000	.00000	.00000	.00000
C	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DD	1	.00464	.00772	.00440	.00550	.00508	.00342	.00194	.00357	.00622	.00598	.00401	.00249	.00122	.00056	.00137	.00245
DD	2	.00524	.01361	.01615	.01157	.00756	.00731	.00116	.00324	.01225	.01566	.00929	.00767	.00217	.00291	.00372	.00221
DD	3	.01056	.01407	.00791	.00418	.00351	.00152	.00011	.00150	.01596	.03510	.01843	.00981	.00543	.00543	.00510	.00176
DD	4	.00416	.02207	.00644	.00104	.00064	.00047	.00001	.00037	.00528	.02164	.02076	.01494	.00441	.00148	.00129	.00163
DD	5	.00110	.00134	.00081	.00000	.00000	.00000	.00000	.00000	.00009	.00275	.00716	.00535	.00105	.00027	.00001	.00000
DD	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00024	.00267	.00040	.00000	.00000	.00000	.00000
DN	1	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	3	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
EF	1	.00919	.02412	.04174	.02101	.01249	.00811	.00479	.00725	.01571	.01139	.00708	.00215	.00102	.00156	.00120	.00243
EF	2	.00740	.01767	.02520	.00995	.00351	.00131	.00070	.00204	.01255	.01464	.00739	.00140	.00222	.00232	.00274	.00167
EF	3	.00174	.00481	.00397	.00121	.00006	.00000	.00000	.00005	.00155	.00402	.00159	.00029	.00035	.00004	.00079	.00013
EF	4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
EF	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
EF	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000

* Ref. : Predictions of annual sulfur dioxide concentrations for Frankfurt am Main, FRG, August 1971 to July 1972, Texas Air Control Board, August 1976.

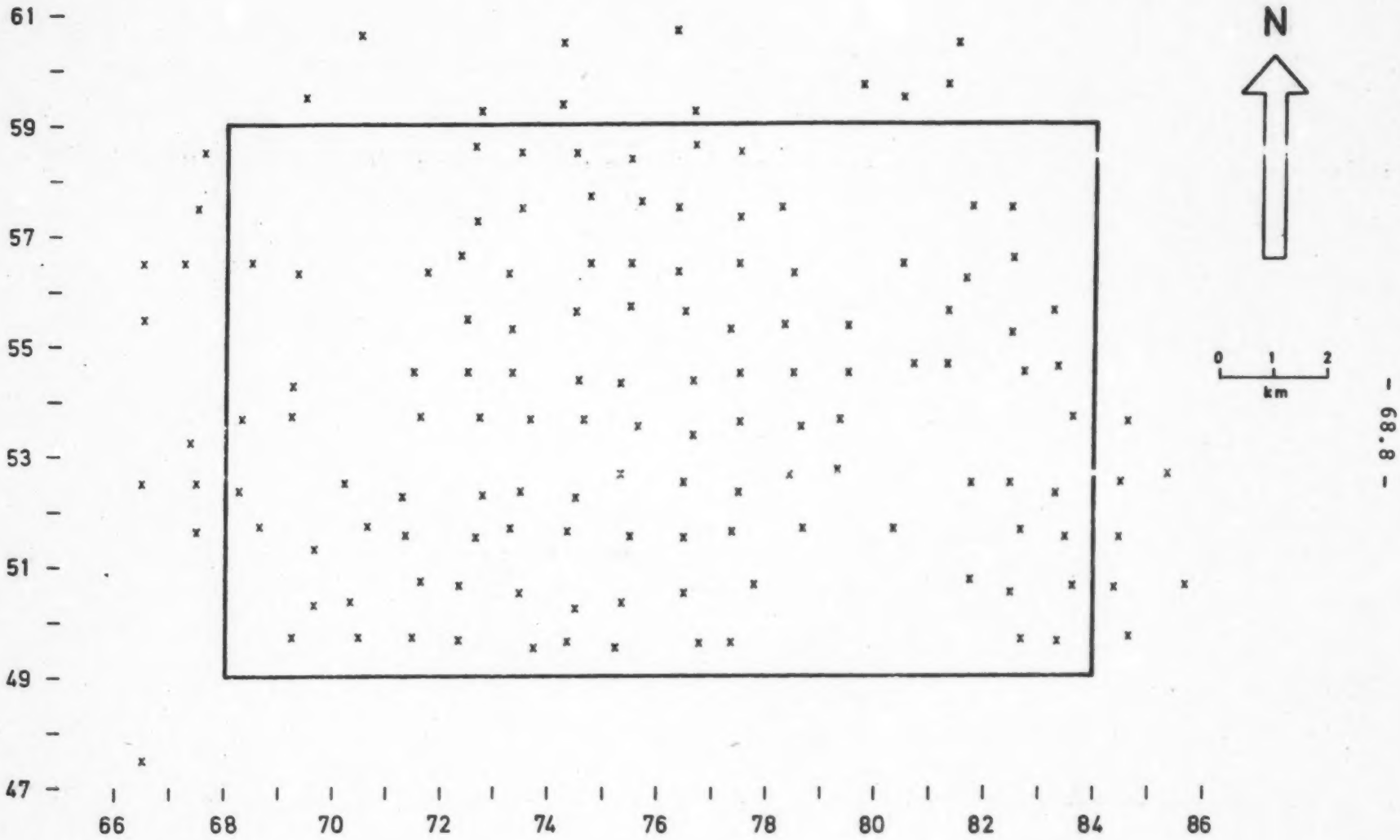

Figure 1 : Distribution of the area sources used as virtual point sources.

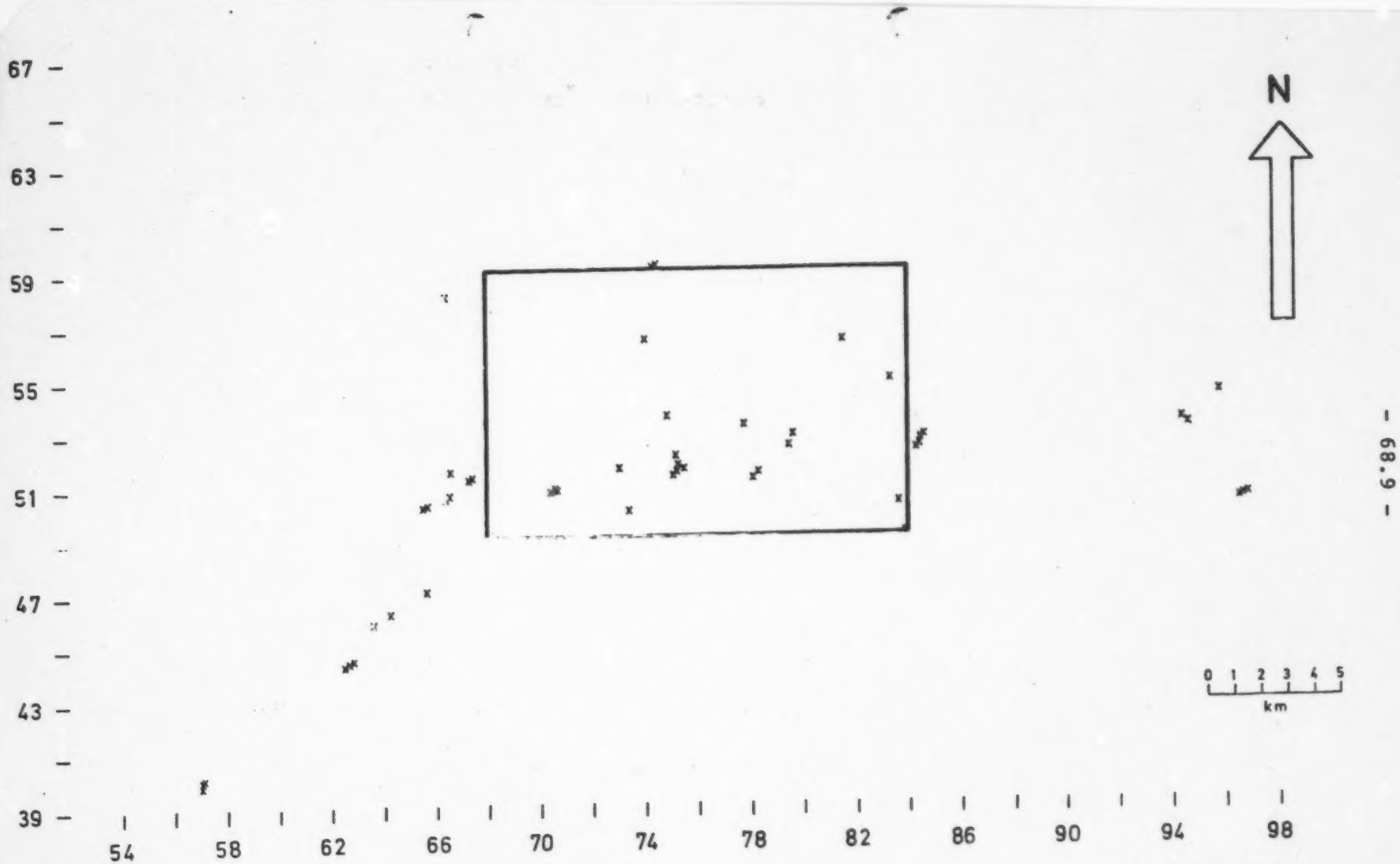

Figure 2 : Distribution of the industrial point sources actually taken into account.

Kretzschmar

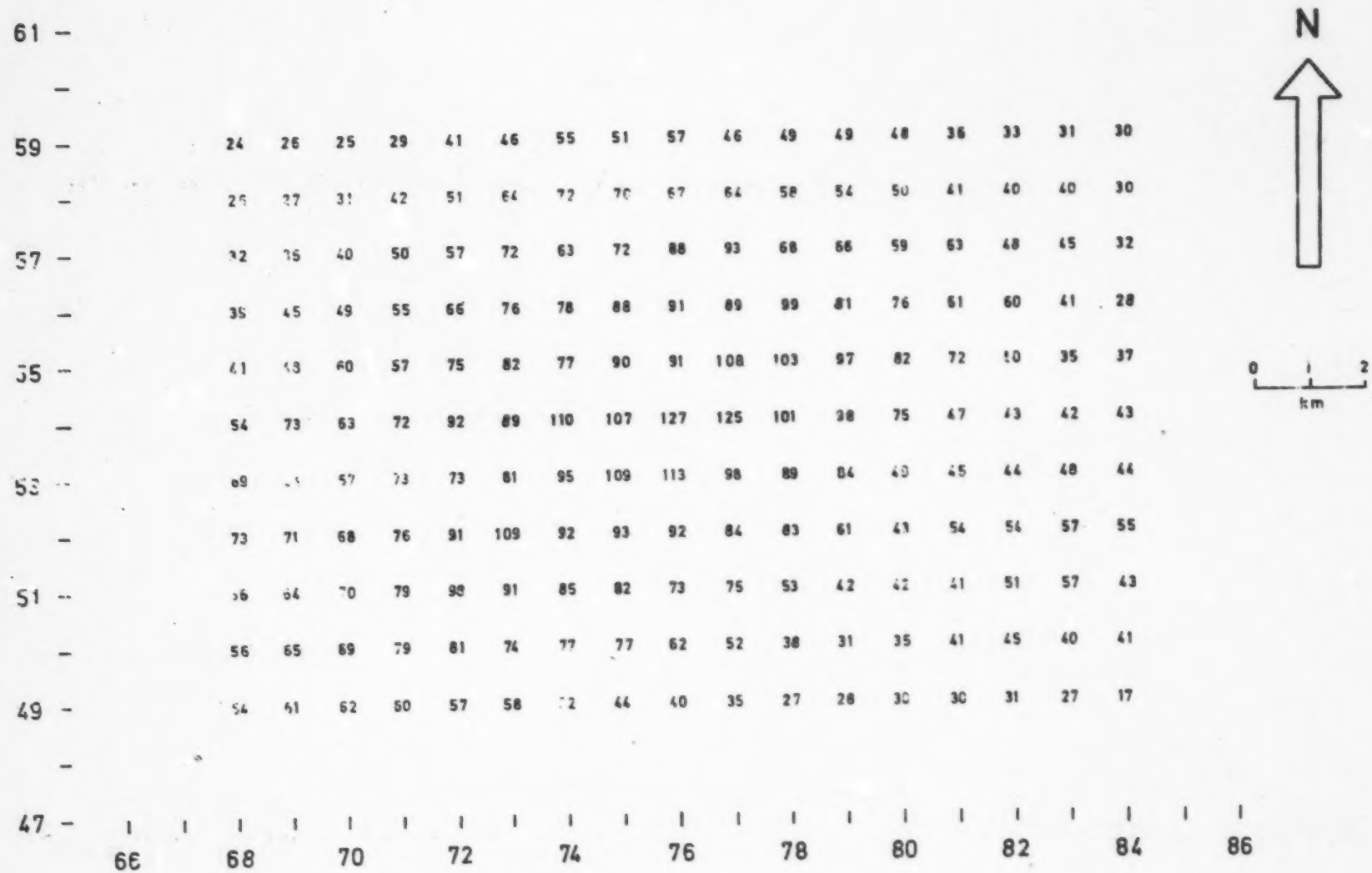

Figure 3 : Calculated average SO_2-concentrations in the grid points of the region under investigation.

APPENDIX

MMUM 7

Type: IMMISSION FREQUENCY DISTRIBUTION MODEL (IFDM)
S.C.K.-C.E.N. Belgium

Gaussian model (1972)

Abstract

The IFDM-model calculates ground level concentrations for one pollutant coming from point and area sources

Characteristic for the model are the following steps :

- 1 : for a given set of emission data, pollution maps are calculated for specific combinations of representative meteorological situations.

  2 : on the basis of the actual meteorological data for a particular period in a given region, an ensemble of the relevant pollution maps is made.

- the plume rise formula of Stümke II is used.

- a vertical windprofile (exponential law) is applied.

- the pollutant is passive.

- the topography can be included.

- the earth surface and the top of the mixing layer are acting as perfect reflectors for the pollutant under investigation.

- area sources are simulated by touching circles wherein the population density can be considered homogeneous.

Results

For each grid point of a regular network with maximum 16 x 21 meshes of n km^2, complete statistics of individual concentrations for a given averaging time (1 hour $\leq t_{av} \leq$ 1 year) and for a specified period (≤ 3 years) are calculated (averages, standard deviations, maxima and percentiles)

Applications

Evaluations of the influence of a new or existing point or area source upon the pollution levels in a given region.

Basic equations <u>Continuous point sources</u>

$$\chi_i\,(x,y,o) = Q_i\ \delta^{-1}\,(x,y,o)$$

$$= \frac{Q_i}{\pi\ \bar{u}(h_e)\ \sigma_y\ \sigma_z}\ \exp\left(-\frac{y^2}{2\ \sigma_y^2}\right)\ \exp\left(-\frac{h_e^2}{2\ \sigma_z^2}\right)$$

<u>Area sources</u>

$$\chi_i\,(o,o,o) = F \times \Big[(A_{1i} + A_{2i}h_e) + (B_{1i} + B_{2i}h_e)\ \sqrt{x_2}$$

$$+ (C_{1i} + C_{2i}\ h_e)\ x_2\ \Big] / \bar{u}(69)$$

for a point inside the circle.

with A_{ji}, B_{ji}, C_{ji}, $j = 1,2$

For a point outside the circle the formula is

$$\chi_i(o,o,o) = F \times \Big[(B_{1i} + B_{2i}\ h_e)\ (\sqrt{x_2} - \sqrt{x_1})$$

$$+ (C_{1i} + C_{2i}\ h_e)\ (x_2 - x_1)\ \Big] / \bar{u}(69)$$

<u>Plumerise formula (Stümke II)</u>

$$\Delta h = \frac{1{,}5 v_s d + 65\ d^{1,5}\ (\Delta T/T_s)^{0,25}}{\bar{u}(h_g)}$$

other formulas can be used.

Meteorological parameters

Diffusion parameters

$$\sigma_y = A\,x^a \qquad \sigma_z = B\,x^b$$

with A, a, B, b depending on the stability classes E_i

Horizontal windfield

subdivided into p wind speed classes ($p \leq 5$)
and q wind direction categories ($q < 36$)

Windprofile

$$u(z_2) = u(z_1)\left(\frac{z_2}{z_1}\right)^{m_1}$$

m_1 is a function of E_1

Stability classes

7 classes E_i. Six classes are defined by the stability parameter $S = \frac{\partial\theta/\partial z}{\bar{u}(69)^2}$ while the seventh one is linked to average wind speeds larger than 11 m/s.

Discretisation for wind direction

Intervals of φ degrees are used ($\varphi \geq 10°$)

Mixing height

Freely chosen

Input data

Emission

Data for the point sources

- a reference number
- the geographical position in Belgian Lambert co-ordinates
- the geometrical height (m)
- the inner diameter of the orifice of the stack (m)
- the temperature of the effluents (°K)
- the total emission rate (Nm^3/s)
- the pollutant rate (kg/s)
- the height a.s.l. of the base of the chimney (m)

Data for the area sources

- geographical position of the centre of the circle in Belgian Lambert co-ordinates
- the mean height of the chimneys inside the circle (m)
- the radius of the circle (km)
- the population density (inh/ha)
- the mean height a.s.l. of the area inside the circle (m)

Immission

Cumulative frequency distributions

Meteorology

For the pollution maps

- the mean wind speed of each class
- the wind direction factor (defines the number q of wind direction categories)
- the mixing height
- the values of m_i for the wind profile
- the discretisation angle φ
- the height of the level of the measured values for wind speed
- the temperature

For the statistics

- a set of measured values of wind speed, wind direction, temperature and stability class (averages over a time t_{av}) over a period T

Program description

User's guide with complete description of the input data.
Maximum 200 point sources for one run.
The number of area sources is limited to 999.
The maximum number of grid points is 3/4 (17 x 21)
Individual chimneys can be subtracted or added.

Output

Numerical output or graphical display

List of symbols

$x_i(x,y,z)$	: average concentration of pollutant P_i at the point (x,y,z)
Q_i	: emission rate of pollutant P_i
$\delta^{-1}(x,y,z)$	: meteorological factor describing the atmospheric diffusion
$\bar{u}(z)$	: mean wind speed at height z
σ_y, σ_z	: horizontal and vertical diffusion parameters
h_e	: effective stack height
F	: correction factor comprising - the real population density - the physical temperature of the specified period
x_1	: upwind distance between the receptor point and the nearest point of the circle ($x_1 = 0$ for a point inside the circle)
x_2	: upwind distance between the receptor point and the farthest point of the circle
Δh	: plumerise ($= h_e - h_g$)
v_s	: exit velocity of the gases
d	: inner diameter of the orifice of the stack
ΔT	: $= T_s - T$
T_s	: temperature of the stack gas
T	: temperature of the ambient air
h_g	: geometrical stack height
$\partial\theta/\partial z$	: potential temperature gradient

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Christiansen, Porter; USA (2x)

PREDICTIONS OF ANNUAL SULFUR DIOXIDE CONCENTRATIONS FOR FRANKFURT AM MAIN, FEDERAL REPUBLIC OF GERMANY, AUGUST, 1971 TO JULY, 1972

Performed by the Texas Air Control Board

in support of the

Practical Demonstration of Urban Air Quality Simulation Models

for the

NATO/CCMS Air Pollution Pilot Study

Texas Air Control Board
Austin, Texas, U.S.A.
August, 1976

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I. INTRODUCTION

The Texas Air Control Board was asked to exercise the Gaussian plume air pollution dispersion models developed by the agency as a part of the Practical Demonstration of Urban Air Quality Simulation Models, in the NATO/CCMS Air Pollution Pilot Study. The tasks facing the participants in the Practical Demonstration were to estimate annual mean concentrations and concentration frequency distributions for sulfur dioxide in a study area centered on Frankfurt am Main, in the Federal Republic of Germany. The data base consisted of a meteorological joint frequency function and average SO_2 emissions data for area and point sources for the period August 1971 to July 1972. Two dispersion models were used, the Texas Climatological Model (TCM; Christiansen and Porter, 1975), for annual mean concentrations, and the Texas Episodic Model (TEM; Christiansen, 1976), for short-term concentrations. For the Frankfurt study, the TEM was linked to a frequency distribution postprocessor (FRED). The TEM/FRED system is, in effect, a climatological model, generating long-term average concentrations and complete details on predicted concentration frequency distributions for a large number of receptor locations. Using the two models, concentrations and important parameters of the frequency distribution were obtained for 242 receptor locations spaced 1.0 km. apart in a uniform grid covering the study area, in addition to six locations specified in the Standard Data Base documentation. The spatial variations across the study area of many statistical parameters related to the frequency distribution were displayed on contour plots.

Section II of this paper briefly describes the Standard Data Base for the Frankfurt study, and the processing it received at the Texas Air Control Board before being used as model input. Section III presents the salient features of the computer programs used in the study: TCM, TEM, and FRED. Section IV covers the methodology of the study. Section V is an exposition of frequency distribution theory as used in the postprocessor (FRED), and Section VI discusses the results of the study.

II. STANDARD DATA BASE FOR FRANKFURT

The entire Frankfurt data base was made available to the Texas Air Control Board in machine-readable form thanks to the efforts of the Meteorology and Assessment Division, Environmental Applications Branch, U.S. Environmental Protection Agency.

Weather Data

The weather data for the Practical Demonstration consisted of a meteorological joint frequency function for the period August, 1971 to July, 1972, divided into 30 wind speed classes (1-30 knots), 36 wind direction sectors and seven Turner stability classes. The U.S.E.P.A. restructured the data somewhat, for use by a variant of their Climatological Dispersion Model (CDM; Busse and Zimmerman, 1973), and this modified data was input to JFFCON, the Texas Air Control Board's joint frequency function conversion program. JFFCON produced a 16 direction x 6 speed x 6 stability class joint frequency function for input to the TCM and TEM/FRED system. No data was provided on mixing height or temperature (an annual mean of 10.2°C was eventually used), and there was no information on seasonal variations.

Area Source Data

The area source inventory consisted of 1457 sources, each with dimensions of 500 x 500 meters. In addition to the emission rate and location of each source, the geometric mean building height within each source square was supplied. Emission rates were converted to annual average, in grams/second, and 386 sources located more than four kilometers from the edge of the study area were deleted.

Point Source Data

The point source inventory contained the locations, heights, diameters, velocities, temperatures, and summer, winter and annual SO_2 emission rates of 681 point sources. Of these, only 307 had emission rates of 0.1 g/s or more, and only 91 were rated at 1.0 g/s or more. Comparison of TCM runs using various sets of point sources alone vs point and area sources together

revealed the following, with respect to annual arithmetic mean SO_2 concentrations:

1) Point sources are a significant influence in Frankfurt, but not a dominant one (compare Figures 2 and 4);
2) Most of the point source concentration is contributed by the 91 largest sources (compare Figures 2 and 3);
3) The 216 sources with emission rates between 0.1 and 1.0 g/s are worth taking into account, but just barely. The sources under 0.1 g/s can be neglected.

Accordingly, the point source inventory used throughout the rest of the study consisted of the 307 sources with emission rates of 0.1 g/s or more.

III. DETAILS OF THE COMPUTER MODELS

The Texas Climatological Model(TCM)

The TCM is a long-term model which calculates concentrations of from one to three pollutants at up to 2500 locations in a uniform grid of arbitrary dimensions and spacing. Input consists of square area sources of any size, point sources, receptor data, if desired, and a 576-element meteorological joint frequency function, all in CDM format.

Area sources are handled by an extremely simple algorithm proposed by Gifford and Hanna (1973). The concentration due to area sources is given by

$$\chi_A = FQ/U \qquad (1)$$

where χ_A = concentration, $\mu g/m^3$,

Q = area source emission rate in the vicinity of the receptor, $\mu g/m^2/s$,

U = mean ground-level wind speed, m/s,

F = a dimensionless constant.

Gifford and Hanna have suggested a value of F=50 for SO_2. This value is used throughout the Frankfurt study. The area emission rate, Q, is determined by averaging the emissions in the area source square containing the

receptor and in the neighboring squares. The extent of the region around each receptor to use for emission rate averaging is an input parameter. Although the area sources read into the TCM may be of any location and size, their emissions are apportioned to a uniform grid of squares, with up to 50 rows and 50 columns of squares. The dimensions and square size of the grid are input parameters. The grid serves an additional purpose. Concentrations are calculated at the center of each grid square. Thus, the TCM can predict concentrations for as many as 2500 receptor points.

The TCM uses steady-state Gaussian plume point source logic, with the crosswind distribution averaged across 22°.5 azimuthal sectors. The only meteorological input required for area source calculations is the mean wind speed, but the point source calculations require a meteorological joint frequency function with 16 22°.5 wind sectors, six wind speed classes (0-3, 4-6, 7-10, 11-16, 17-21, and >21 knots), and six stability classes (Turner classes A,B,C,D(day),D(night), and E plus F). Let the concentration due to point source i be given by

$$\chi = (16\times10^6/2\pi) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi(k_i,\ell,m)\, Q_i S/x, \qquad (2)$$

$$S = (2/\sqrt{2\pi}\, U_\ell \sigma_z) \exp(-H_i^2/2\sigma_z^2) \exp(-.692x/U_\ell T_{\frac{1}{2}}) \qquad (3)$$

with χ = concentration, $\mu g/m^3$,

k_i = the wind sector index appropriate to source i at the receptor

l = wind speed class index,

m = stability class index,

ϕ = meteorological joint frequency function,

Q_i = emission rate of source i, g/s,

H_i = effective height of source i, m,

σ_z = standard deviation of vertical Gaussian concentration distribution, m,

$T_{1/2}$ = half-life for first-order pollutant decay, s,

U_l = central wind speed of class l, m/s,

x = downwind distance, m.

This is the form used by the CDM. The TCM defines a wind speed U_m characteristic of an entire stability class :

$$U_m = [\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi(k,\ell,m)] [\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi(k,\ell,m)/U_\ell]^{-1}, \quad (4)$$

This allows the reduction of ϕ (k,l,m) to ϕ (k,m), with each frequency of the new 96-element joint frequency function being the sum of the six wind speed class elements for each stability class / wind sector combination.

Then

$$\chi = (16x10^6/2\pi) \sum_{m=1}^{6} \phi(k_i,m) Q_i S/x, \quad (5)$$

$$S = (2/\sqrt{2\pi}\, U_m \sigma_z) \exp(-H_i^2/2\sigma_z^2) \text{ (decay term)}. \quad (6)$$

Define K =

$$K(x,H,m) = (32x10^6/(2\pi)^{3/2} x\, \sigma_z) \exp(-H_i^2/2\sigma_z^2). \quad (7)$$

Then finally,

$$\chi = Q_i \sum_{m=1}^{6} (K(x,H,m)\phi(k,m)/U_m) \text{ (decay term)}. \quad (8)$$

For the TCM, K was precalculated for twenty downwind distances, x = 0.1 to 46.1 km, nine effective source heights, H = 10 to 300 m, and the six stability classes mentioned above. These 1080 K-values (20x9x6) are stored as data tables in the TCM. The dispersion equation (8), is solved by interpolation in the K-tables rather than the time-consuming explicit calculation of the exponentials in equations (2) and (3). Decay terms are also precalculated.

The dispersion parameter σ_z in equation (7) is calculated as in the CDM:

$$\sigma_z = ax^b, \tag{9}$$

with Busse and Zimmerman's tabulated values of the stability and downwind distance - dependent coefficients a and b.

A Briggs (1969) plume rise formulation is used :

$$H = h+\Delta h,$$

$$\Delta h = 1.6\ F^{1/3}\ (3.5x^*)^{2/3} U^{-1}$$

$$x^* = 14F^{5/8} \text{ if } F \leq 55,$$

$$x^* = 34F^{2/5} \text{ if } F > 55. \tag{10}$$

$$F = gvr^2(T-T_{ambient})/T,$$

Here H = effective source height, m,

h = physical source height, m,

Δh = plume rise, m,

g = 9.8 m/s^2

v = source exhaust velocity, m/s

r = inside radius of source, m,

T = source temperature, °K

Tambient = ambient temperature, °K

The wind speeds U_1, etc, in equations (3), (4), (6), (8) and (10) are the speeds at the physical height of the source. They are derived from the ground-level wind speed via

$$U = U_o(z/z_o)^P \tag{11}$$

where U = wind speed at height z, m/s,

U_o= surface wind speed, m/s,

z = height, m,

z_o= anemometer height,m. z_o is set equal to 10m.

P = an exponent dependent on stability class (Busse and Zimmerman, 1973)

Up to five meteorological joint frequency functions along with five sets of point sources and five sets of weighting factors for one set of area sources may be input to the TCM in one computer run. The usual application of this feature is for annual and seasonal predictions for the same study area. There is no limit to the number of area or point sources which may be used as input.

The TCM is "self-calibrating", performing (on request) a first-order least squares regression analysis on calculated vs. observed concentrations in the same computer run.

TCM output is available in any combination of the following four forms:

1. List of predicted concentrations by receptor, one receptor grid column per page.
2. Printer map of the concentrations across the receptor grid, suitable for hand isoplething.
3. Culpability list of the five sources contributing the most to the total concentration at each receptor.
4. Punched cards for computer contour plotting.

Due to the highly efficient area and point source logic and the simplification of the joint frequency function, the TCM gives essentially the same results as the CDM, but is some 80 to 400 times faster.

The Texas Episodic Model (TEM)

The TEM is a short-term companion model to the TCM. Both models can use the same source input and have the same options available for displaying output. The TEM calculates concentrations of one or two pollutants at up to 2500 locations in a uniform grid of arbitrary dimensions and spacing Input consists of square area sources of any size, point sources, and weather data for up to 24 weather "scenarios" for which concentrations are predicted, for sample times of from 10 minutes to 3 hours, with provisions for simulating a 24 hour day through superposition of eight scenarios representing

three hours each, or 24 scenarios representing one hour each. Information required for each scenario includes stability class, wind speed, wind direction, ambient temperature, first-order decay half-lives of the two pollutants, mixing height, and an "inversion penetrability factor" which controls the strength of the inversion. An option allows the TEM to search through four or sixteen different wind directions in each weather scenario instead of the direction specified for the scenario. The sixteen-direction option is used when the TEM is linked with FRED, the frequency distribution postprocessor, to form a climatological model.

Area sources are input as squares of arbitrary size and location. Their emissions are reapportioned by the TEM into a uniform grid of squares, and the area source algorithm operates on this uniform grid. As with the TCM, the grid contains up to 50 rows and 50 columns of squares of any size, and concentrations are calculated at the center of each grid square. The area source algorithm is due to Gifford and Hanna, (1970). Each area source square is affected by its own diffuse emissions and those in the N area source square directly upwind of it:

$$\chi = \sqrt{\frac{2}{\pi}} \frac{(\Delta x/2)^{1-b}}{U_o a(1-b)} \left\{ Q_o + \sum_{i=1}^{N} Q_i \left[(2i+1)^{1-b} - (2i-1)^{1-b} \right] \right\} \qquad (12)$$

with

Δx = length of side of area source grid squares, m,

U_o = surface wind speed, m/s,

Q_o = area emission rate of square containing the receptor, $\mu g/m^2$,

Q_i = area emission rates of the upwind area sources, $\mu g/m^2$,

a,b as in equation (9).

In the TEM, N=4. For each wind direction, every area source square lays down the same concentration pattern, scaled by Q. There are 10 possible patterns for N=4, stored as data in the model. To simplify the calculations, equation (12) is used in a source-oriented instead of a receptor-oriented manner-- that is, each source square affects itself and the four squares downwind of it.

A modification was made to the area source algorithm to take into account the nonzero emission heights of the Frankfurt area sources. The Frankfurt area source inventory included the geometric mean height of the buildings in each area. Since the area emissions are due almost entirely to residential combustion, it was decided to use the geometric mean height as the effective source height. Accordingly, 50 factors f_H, defined in equation (13) below, are calculated for each scenario for squares zero through four, at ten different effective source height classes up to 50 meters:

$$f_H = \exp(-H_A^2/2\sigma_z^2), \tag{13}$$

with H_A = effective height of the area source, m,
σ_z as defined in equation (9),m.

The contributions of an area source to the concentrations in its own square and in the four downwind squares are scaled by the five f_H values for the effective source height class of the area source. The downwind distances used to calculate σ_z in equation (13) for square 0 to 4 respectively are $\Delta x/4$, Δx, $2\Delta x$, $3\Delta x$, and $4\Delta x$. A trigonometric adjustment is made to Δx when the wind direction is not directly down a row or column in the area source grid. Also, to simulate urban roughness, the atmospheric stability is decreased by one class for the area source calculations.

The TEM employs steady-state bivariate Gaussian plume point source logic. The concentration due to an elevated point source is given by

$$\chi = \frac{10^6 Q}{\pi\sigma_y\sigma_z U}\exp(-y^2/2\sigma_y^2)\exp(-H^2/2\sigma_z^2)\exp(-.692x/UT_{\frac{1}{2}}) \tag{14}$$

where
χ = concentration, $\mu g/m^3$,
Q = emission rate, g/s,
U = wind speed at physical source height, m/s,
H = effective source height, m,
x = downwind distance, m,
y = crosswind distance, m,
$T_{\frac{1}{2}}$ = first-order pollutant decay half-life, s,

σ_y, σ_z are the standard deviations of the Gaussian concentration distribution, respectively:

$$\sigma_z = ax^b, \tag{15}$$

$$\sigma_y = cx^d, \tag{16}$$

with stability and downwind distance-dependent coefficients a, b, c and d from Busse and Zimmerman (1973) and Turner (1970). The wind speed U is obtained from the surface wind speed through equation (11).

$$K_y = \frac{1000}{\sigma_y} \exp\left(-y^2/2\sigma_y^{\ 2}\right), \tag{17}$$

$$K_z = \frac{1000}{\pi\sigma_z} \exp\left(-H^2/2\sigma_z^{\ 2}\right), \tag{18}$$

Then equation (14) becomes

$$\chi = \frac{K_y K_z Q}{U} \text{ (decay term)} \tag{19}$$

K_y was calculated for each of the 1120 combinations of twenty downwind distances from 2 to 60 km, eight crosswind angles ($\mathrm{Tan}^{-1}y/x$) from 0 to 7δ, with δ varying from 1 to 5° depending on stability, and seven stability classes (A,B,C,D(day),D(night),E and F). K_z was calculated for each of the 1960 combinations of the same twenty downwind distances, fourteen effective source heights from 10 to 2000 meters, and seven stability classes. These 3080 values are stored in the TEM as data tables. For downwind distances over 2 km, concentrations are calculated by interpolating for the K_y and K_z values appropriate to a given downwind distance, crosswind distance, effective source height, and stability class. Decay factors for each distance are precalculated for each scenario. Such calculations are considerably faster than the explicit solution of equation (14). For downwind distances of less than 2 km, interpolation is not considered sufficiently accurate, so equation (14) is used.

Turner's (1970) treatment of mixing height is used in the TEM. For total vertical mixing below a mixing height of L meters,

$$\chi = \frac{10^6 Q}{\sqrt{2\pi}\sigma_y LU} \exp\left(-y^2/2\sigma_y^2\right), \tag{20}$$

or, in terms of equations (17), (18) and (19),

$$K_z \simeq 398L \tag{21}$$

At $x>2x_m$, where x_m is a distance such that $\sigma_z=0.47L$, equation (20) is used. For $x_m \leq 2x_m$, interpolation between results of equations (14) and (20) is employed.

An inversion penetration factor, I, is a program input for each weather scenario. If $H>LI$, the plume escapes the mixing layer. If $L<H\leq LI$, the plume does not escape, and H is set equal to L. Typically, $I\simeq 2$.

Plume rise is calculated by one of six formulae, all due to Briggs, (1969). The program chooses the correct formula on the basis of 1) downwind distance, 2) atmospheric stability, and 3) whether the rise of the plume is dominated by thermal buoyancy or momentum. Figure 1 shows the six equations, with the conditions under which they are used.

The TEM has the same options for displaying output as the TCM. The concentrations may be listed, displayed in a printer map, and/or punched onto cards for plotting, and a culpability list of the five sources contributing the most to the total concentration at each receptor may be requested.

Use of equation (19) for point sources and the relatively simple algorithm for area sources make the TEM approximately three to five times faster than other similar but less sophisticated short-term models tested at the Texas Air Control Board, while the careful treatment of plume rise greatly enhances its accuracy.

	STABLE AIR	UNSTABLE AIR
BUOYANCY-DOMINATED	$\Delta h(x) = 1.6F^{1/3}\, x^{2/3} U^{-1}$ (22) or $\Delta h_{MAX} = 2.4[F/US]^{1/3}$ (23) where $S = 0.02g/T_A$, E stability, $S = 0.035g/T_A$, F stability.	$\Delta h(x) = 1.6F^{1/3}\, x^{2/3} U^{-1}$ (22) for $x < 3.5x^*$, or $\Delta h_{MAX} = 1.6F^{1/3}(3.5x^*)^{2/3} U^{-1}$ (24) for $x > 3.5x^*$. $x^* = 14F^{5/8}$ if $F < 55$, $x^* = 34F^{2/5}$ if $F > 55$.
MOMENTUM-DOMINATED	$\Delta h_{MAX} = 1.5(VR)^{2/3} U^{-1/3} S^{-1/6}$ (25) S as above.	$\Delta h(x) = 3.78\left(\frac{V^2}{U(V+3U)}\right)^{2/3}\left(\frac{xR^2}{2}\right)^{1/3}$ (26) or $\Delta h_{MAX} = 3VD/U$ (27)

$F = gVR^2(T-T_A)/T$.

T = source temperature, °K.

T_A = ambient temperature, °K.

V = velocity, m/s.

R = radius, m.

D = diameter, m.

x = downwind distance, m.

U = wind speed at physical source height, m/s.

g = acceleration due to gravity, 9.8 m/s^2.

FIGURE 1. TEM Plume Rise Formulae

The Frequency Distribution Postprocessor (FRED)

FRED (FREquency Distribution) is a computer program which was designed to give the Texas Air Control Board the ability to construct and analyze predicted concentration frequency distributions without having to develop a new dispersion model to generate them. In the system which was devised to meet these needs, the Texas Episodic Model (TEM) is linked with FRED to form a climatological model with frequency distribution creation and analysis capabilities.

The first step in the operation of the TEM/FRED system is the prediction of concentrations for every set of weather conditions encountered in the meteorological joint frequency function. The TEM/FRED system uses the the same joint frequency function as the TCM, with 16 wind directions, six wind speed classes, and six stability classes. The TEM is run to predict short-term concentrations for each weather situation. In TEM input, one scenario card is required to create each weather scenario of wind direction, wind speed, stability, temperature, mixing height, etc. for which concentrations are to be calculated. Using an input option originally designed to search for worst-case wind directions in complicated source distributions, one scenario card can generate 16 scenarios with 16 different wind directions (at the compass points) with the other weather parameters fixed. With this option, all 576 weather situations in the joint frequency function can be modeled using just 36 scenario cards, each one representing a particular stability class/wind speed combination for all wind directions. Thus up to 36 separate values of mixing height, temperature, and decay half-lives may be input for one climatological simulation. Data available for the Frankfurt study was of insufficient detail for much advantage to be taken of this feature. In practice, fewer than 36 scenario cards are necessary, since several stability/speed combinations are not naturally occurring. The predicted concentrations for each weather condition at each of up to 2500 receptors are transmitted by the TEM to magnetic disk or tape files for subsequent input to FRED. In practice, mass storage and computer time considerations limit the TEM/FRED system to dealing with a few hundred receptors at a time (242 for the Frankfurt study). It should be noted at this point that the operation of

FRED is entirely transparent to the TEM. The TEM is simply producing a large volume of short-term concentration predictions. It required virtually no modifications to operate with FRED. The joint frequency function is an input to FRED, not the TEM-- the latter predicts concentrations without needing to know their frequency of occurrence. Also worthy of note is the point that, since the TEM is predicting concentrations for wind directions directly down the center of each of the 16 wind sectors (0°, 22.5°, 45°, etc.) rather than averaging across the width of each sector, it is, in effect, sampling the annual weather. It is possible that this will yield somewhat larger variances in the concentration frequency distribution than climatological models with crosswind distributions averaged across wind sectors.

Input to FRED includes the files containing the concentrations predicted by the TEM, the meteorological joint frequency function for the study area, and a set of parameters governing various options on processing the frequency distribution.

The following is a list of the processing sequence for a computer run of FRED when all options are requested:

1. Read control parameters (number of receptors, width of concentration intervals for histograms, specific cumulative frequency levels at which to calculate concentrations, etc.).

2. Read meteorological joint frequency function of normalized frequencies of occurrence of 576 possible weather situations, print.

3. Read TEM-predicted concentrations for each of 576 possible weather situations at up to 50 receptors at a time, print.
   (The limit of 50 is imposed by the size computer core storage at the Texas Air Control Board -- 576x50 = 28,800 values) If desired, analysis can be done on receptor locations between the receptor grid points of the TEM. This is accomplished by interpolating among the concentrations predicted at the four surrounding receptor grid points.

4. For each receptor:
   a) Calculate arithmetic mean and standard deviation of the concentration frequency distribution, print.
   b) Calculate geometric mean and standard deviation for lognormal delta-distribution (see Section V), print.
   c) Calculate expected second-highest 24 hour concentration for the year, based on lognormal delta-distribution defined by geometric mean and standard deviation, print.
   d) Calculate geometric mean and standard deviation from arithmetic mean and standard deviation assuming lognormality (after Larsen, 1971), print.
   e) Calculate expected second-highest 24 hour concentration for the year based on parameters calculated in 4d, print.
   f) Group the frequencies into uniform concentration intervals.
   g) Calculate cumulative frequency distributions from grouped data.
   h) Conduct Kolmogorov-Smirnov test (see Section V) for goodness of fit of cumulative frequency distribution from 4g to cumulative frequency distribution from integration of the lognormal function derived in 4d, at four significance levels, print results.
   i) Conduct Kolmogorov-Smirnov test for goodness of fit of cumulative frequency distribution from 4g to cumulative frequency distribution from integration of the lognormal function derived in 4b, at four significance levels, print results.
   j. Print histogram of predicted concentration frequency distribution, with lognormal function superimposed.
   k) Print cumulative frequency distribution at 50 concentration levels for both grouped data and lognormal fit.
   l) Calculate concentration at up to three specified cumulative frequencies, from the grouped data.

5. Print a summary of receptor coordinates and results of 4a, b, c, d, e, l. Punch the same information onto cards for computer contour plotting. All of the "TEM" contour plots in this paper were generated from this output.

IV. METHODOLOGY FOR THE PRACTICAL DEMONSTRATION

The study area for the Practical Demonstration was defined as extending from 3465.0 to 3484.0 km east, and from 5549.0 to 5559.0 km north, in the Gauss-Krueger coordinate system. It was decided to use the same grid of receptor points for both the TCM and TEM model runs, covering the study area with 242 receptor points in 11 rows and 22 columns, spaced 1.0 km apart, and reaching from 3465 to 3486 km east, 5549 to 5559 km north.

For the TCM simulations SO_2 half-life was taken as 6.0 hours. The area source F-value (see equation (1)) was set at 50.0. The radius around each receptor within which to average area source emissions for equation (1) was allowed to vary. Area emission radii of 1.5, 2.5 and 3.5 km, corresponding to averaging emissions in the 9,25, and 49 1.0 km area source squares centered on the receptor's square, respectively, were tried. The Standard Data Base for Frankfurt contains 500 m area sources, so each 1.0 km source in the TCM and TEM may contain as many as four separate sources. These are simply averaged in the TCM, but are considered individually in the TEM due to differences in effective emission height.

In the TEM, SO_2 half-life was varied with stability class, on the assumption that SO_2 decay rate is a function of insolation. The half-life values were 2.0 hours for A and B stability, 4.0 hours for C, 6.0 hours for D and 10.0 hours for E and F.

Since no mixing height data was available, mixing height was allowed to default to 10,000 m in all cases.

To reflect the increased turbulence of the urban atmosphere in Frankfurt, D(day) dispersion was used for all D stability scenarios, and E dispersion was used for all E and F stability scenarios.

The TEM generated a map of the concentrations predicted for every weather situation with a non-zero frequency of occurrence. While these maps are useful in the analysis, they are not included in this paper, since there are over 200 of them.

FRED, the frequency distribution postprocessor, constructed and analyzed concentration frequency distributions for all 242 receptor points, as well as the six special test receptors at the Gauss-Krueger coordinates listed below:

3473.29 , 5551.53
3479.25 , 5553.15
3475.76 , 5553.98
3467.00 , 5552.00
3470.00 , 5557.00
3485.00 , 5552.00

The last three locations happen to coincide with receptor locations in the grid. Printout of FRED analysis is available for all receptors, with all output options. Complete FRED output for the six test receptors is included in the Appendix. The Appendix also contains plots of the cumulative frequency distributions for the test receptors.

Pairs of contour plots are included for all three TCM runs (area emission radius = 1.5, 2.5, and 3.5 km), and nine different surfaces resulting from FRED analysis of TEM output. Both plots in each pair show the same isopleths. The first plot of a pair is annotated with geographic features (rivers, city limits, district names, and test receptor locations), while the second plot displays the value of the parameter used to define the surface at each receptor location. For most plots, all 242 receptors are included. For the plots whose dependent variable is a function of the parameters of the lognormal fit, receptors are deleted if their frequency distributions failed either of the Kolmogorov-Smirnov tests for lognormality at any significance level, (see Sections III and V). Only 169 points are plotted for such surfaces, since 73 receptors failed the test.

V. STATISTICAL BASIS FOR THE FREQUENCY DISTRIBUTOR POSTPROCESSOR (FRED)

FRED determines distribution parameters and various concentration level probabilities based on the assumption of lognormality of the distribution data. This section describes the equations used in FRED and the Kolmogorov-Smirnov test.

A. The Form of the Frequency Distribution of Concentrations

Many investigators have studied the frequency distribution of air pollution concentrations, both in theory and as recorded at air pollution monitoring facilities. A wide range of skewed frequency distributions have been proposed or fitted to the empirical data. The distributions investigated include the Weibull distribution (Barlow, 1971; Kilokaj, 1972) and negative binomial distribution (Prinz and Stratman, 1966); but by far the most extensively fitted distributions are lognormal (Neustader, et al, 1974; Knox and Pollack, 1974; Shoji and Tsukatani, 1973) in the multiple source urban environment and exponential (Gifford, 1959; Scriven, 1965; Gartrell, 1966) in an environment dominated by a single source. In the case of the urban environment, the work of R.I. Larsen (Larsen, 1970; 1971) based on analysis of seven years of continuous monitoring data from USEPA monitors in urban areas is the most widely cited investigation of the lognormality of air pollution concentration. Studies by P.J. Barry (Barry, 1971; 1975) support the theory that receptors dominated by a single source record concentrations of pollutants that are exponentially distributed. The work by Barry is based on several years of data using argon-41 injected in the plume of a power plant.

The expected distribution of pollution concentrations in the Frankfurt study area is lognormal because it is an urban environment with many sources contributing to the concentrations at each receptor point. Departures from lognormality of the data that exist may be caused by the receptor dominance by a single or a few sources, causing a trend toward an exponential distribution. Geometric mean, geometric standard deviation, the second-high expected value, and percentile concentrations are

calculated based on the assumption of lognormality of the concentration data. The Kolmogorov-Smirnov test is applied to the data to test for lognormality. Those points that fail the Kolmogorov-Smirnov test are excluded in the isopleth maping of lognormal distribution related parameters.

The parameters of the lognormal distribution (geometric mean and geometric standard deviation) cannot be calculated from aerometric data by the usual equations because the logarithm of the concentration is required in the calculation; therefore, zero valued concentrations cannot be included because ln(0) is undefined. Two methods of calculating the parameters of the lognormal distribution are employed. The methods are: 1) Larsen's Method; 2) the delta distribution.

1). Larsen's Method

Based on the critical assumption that the data fits a two-parameter lognormal distribution, the following transformations can be used to calculate the geometric mean and standard deviation based on the arithmetic mean and standard deviation (Larsen, 1971).

M = arithmetic mean

S = arithmetic standard deviation

$$M = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad (28)$$

x_i = the i th variate of the distribution

N = the number of variates

GM = geometric mean

SG = standard geometric deviation

$$\ln SG = \ln^{0.5}(S^2/M^2+1) \qquad (29)$$

$$\ln GM = \ln M - 0.5\ln^2 SG \qquad (30)$$

The expected second-high 24 hour mean concentration is given by

$$X_{2nd} = \exp(\ln GM + 2.63\ln SG) \qquad (31)$$

2) <u>The Delta Distribution</u>

The delta distribution proposed by Aitchison and Brown (Aitchison and Brown, 1957) is a lognormal distribution that will accept zero elements in the frequency distribution. The delta distribution is a three parameter distribution. The parameters δ, μ, and σ are the proportion of zero variates, the geometric mean of non-zero variates, and the standard geometric deviation of non-zero variates respectively. Aitchison and Brown recommend distribution for cases where zero values are present but the non-zero variates are lognormally distributed.

In a population where the proportion of zero valued variates equals δ, the probability density function (P) is:

$$P(X<0) = 0$$
$$P(X=0) = \delta$$
$$P(X\leq x) = \delta+(1-\delta)F_{LN}(x;\mu,\sigma) \qquad (32)$$

where F_{LN} is the lognormal probability density function (p.d.f.).

$$F_{LN} = \frac{1}{\sigma X\sqrt{2\pi}} \exp(-0.5(\ln X-\mu)^2/\sigma^2) \qquad (33)$$

For a sample S_N where:

N = the sample size

N_0 = the number of zero samples

N_1 = the number of non-zero samples

The joint sufficient estimators of the delta distribution are:

$$\hat{\delta} = N_o/N \qquad (34)$$

$$\hat{\mu} = \bar{y} \qquad (35)$$

$$\hat{\sigma}^2 = V_y^{\ 2} \qquad (36)$$

where

$$y_i = \ln x_i \tag{37}$$

$$\bar{y} = \frac{1}{N_1}\sum_{i=1}^{N} y_i \tag{38}$$

and

$$V_y^2 = \frac{1}{N_1-1}\sum_{i=1}^{N_1}(y_i-\bar{y})^2 \tag{39}$$

B. Application of the Kolmogorov-Smirnov Statistic

The Kolmogorov-Smirnov Statistic (D-Statistic) determines the goodness of fit of a sample distribution to a postulated distribution by testing each element in the sample such that

$$D_\alpha \geq \mathrm{MAX}|S(X)-F(X)| \tag{40}$$

where

D_α = the d-statistic for a given level of significance α

$S(X)$= the sample cumulative distribution function (c.d.f.)

$F(X)$= the postulated c.d.f.

For a normal population the d-statistic is (Lillienfors, 1967)

$$D = \underset{i=1,N}{\mathrm{MAX}}|\Phi(z_i)-i/N| \tag{41}$$

where

$\Phi(z_i)$ = the normal cdf with the standardized variate

$$z_i = (y_i-\mu)/\sigma \tag{42}$$

i= the rank order of the variate being tested

N= the total number of elements in the sample

For the TEM postprocessor application

$$y_i = \ln x_i \tag{43}$$

and

x_i= the i th concentration at the receptor

Using this transformation, equation (41) is suitable for testing the goodness of fit of the sample distribution to a lognormal distribution where

μ = the logarithm of the sample geometric mean

σ = the logarithm of the standard geometric deviation

μ and σ can be estimated either by the method of Larsen or from the lognormal portion of the Δ-distribution. For the purposes of the d-statistic calculation, the Δ-distribution can be considered lognormal because the δ parameter is the same in both S(X) and F(X) of equation (42); therefore, the effect of zero variates cancels.

The table of D_α for various significance levels based on μ and estimated from the sample is (Lillienfors, 1967):

significance level - α

0.2	0.15	0.10	0.01
$\frac{0.736}{\sqrt{N}}$	$\frac{0.768}{\sqrt{N}}$	$\frac{0.805}{\sqrt{N}}$	$\frac{1.031}{\sqrt{N}}$

The meaning of the significance level for this test is that 100 α per cent of the samples from a normal population would be expected to be rejected using this test.

VI. RESULTS OF THE STUDY

This section discusses the results of the study as represented by computer printouts for the six special receptor points (Appendix A) and isopleth maps of the study area (Figures 2-15).

A. Appendix A contains all the data produced by FRED for the six receptor points designated to be of special interest in the study area. Page A-1 lists the input parameters for FRED and the types of output documents produced. Page A-2 lists the receptor points studied. Page A-3 is the stability wind rose joint frequency function for the

Frankfurt area. There follows five pages of data calculated for each receptor point. These receptor data pages are:

p.1) An array containing the concentration calculated for each scenario of meteorological data. It is from this sample set of concentrations that the parameters of the frequency distribution are calculated.

p.2) A listing of the arithmetic and geometric parameters calculated by FRED, and the results of the Kolmogorvo-Smirnov test for lognormality.

p.3) A histogram of the concentrations along with a graph of the delta probability density function.

p.4) The cumulative frequency distribution of the sample and delta function.

p.5) A graph of the sample cumulative frequency distribution (not computer generated).

Receptors 2,3,4 and 6 passed the Kolmogorov-Smirnov test for lognormality at all significance levels. Receptor 1 failed the test with the Larsen-lognormal parameters at significance levels .15 and greater while receptor 5 failed the test at all levels. The delta-lognormal distribution passed the test at all levels for all six receptors. The authors consider that failure of either lognormal distribution to pass the test at any significance level is sufficient cause to assign low credibility to the lognormal distribution based parameters calculated for that receptor. An examination of the histograms and sample concentration arrays for receptors 1 and 5 show how the sample differs from the postulated lognormal distribution.

At receptor 1, the frequency of occurrence of concentrations 120 and 224 are much higher than predicted by the lognormal density function curve (represented by +'s and &'s). The sample concentration array shows that most of the concentrations in the concentration class 112 to 120 $\mu g/m^3$ occur at wind speed class 2 with unstable neutral condition without regard to wind direction. In the 216-224 $\mu g/m^3$ concentration class the wind speed class 1 dominates. Therefore it would appear that the influence of sources at low wind speeds without regard to wind direction influences the concentrations

at receptor 1. At receptor 5, the high frequency of occurrence of concentrations below 8 $\mu g/m^3$ is caused by the positioning of the receptor north of the major sources. Generally without regard to wind speed or stability class high concentrations only occur with southerly winds.

A detailed analysis of each receptor point in the Frankfurt area is available from FRED just as for the six receptors in Appendix A. Obviously, such a large volume of data cannot be included in this report. However, a survey of the 242 receptors in the study area shows that failures of lognormality that occur when the receptor is located near the edge of a built up area typically have data sets much like receptor five. The histogram of receptor 1 is typical of the receptors (relatively few in number) that failed the Kolmogorov-Smirnov test even though they were located well within a built up area. One can speculate that the departure from lognormality in the latter case is due to a domination of the receptor by a few large nearby sources at low wind speeds. In the case of receptors on the edge of built up areas, theory dictates (see Section V) that such a source receptor configuration would cause a tendency toward an exponential distribution.

The validity of the frequency distribution histograms should be questioned because several important factors concerning the input data to the model were smoothed by annual averaging to the point that the frequency distribution predicted by the model may not reflect observed values. The emissions from area sources vary strongly by season and diurnally. The TEM could account for these emission changes if seasonal climatology had been provided. The model could also accept diurnal changes in the emissions and variations in mixing depth. All of these factors could effect the frequency distribution projected by the model since area source emissions are the major contributors to observed concentrations in the study area.

B. Isopleth Maps of the Study Area (Figures 2-15). The isopleth maps of the study area are presented in two formats. The (a) figure shows isopleth contours of the model parameters being presented along with geographical features of the area. The (b) figure presents the value of the model parameter at each grid point (demoted by +'s) along with the isopleths but omitting geographical features.

The results of the TCM study of the area are presented in Figures (4-6). The difference between the values calculated for the arithmetic mean are solely a function of the number of area source grid squares used by the area source algorithm of the TCM. In this study, the radius was given values 1.5, 2.5 and 3.5. Increasing the radius smoothed the dominate area source emissions resulting in lower peak values. Figure 4 using the 1.5 km radius for the area source algorithm resulted in values that most closely resembled the TEM produced arithmetic mean (Figures 7a and 7b). Since the TEM uses a more sophisticated version of the Hanna-Gifford area source algorithm, Figures 4a and 4b are considered the most representative TCM values for the study area.

Figure 8 presents the TEM calculated annual SO_2 geometric means for the study area based on the delta-lognormal distribution function. Figure 9 presents the 60 percentile concentrations (the annual standard for the study area is based on this value). Note that the 60 percentile figures correlate closely with the arithmetic mean values of Figure 7 as expected for the lognormal distribution. The 95 percentile (Figures 10a and 10b) maps relate to the 24 hour standards for the study area. The annual standard (60 percentile) is 140 $\mu g/m^3$ and the 24 hour standard (95 percentile) is 400 $\mu g/m^3$. Figure 11 is the 97.5 percentile concentration. In the case of all percentile figures, those receptors that failed the Kolmogorov-Smirnov test at any significance level for either the Larsen-lognormal or the delta-lognormal distributions were excluded from the isopleth mapping. The extent of receptor exclusion can be seen by the blank grid points in the (b) figures for percentile concentrations. Most of the excluded receptors lie along the edges of the built up areas.

Figures 12a and 12b presents the coefficient of variance for each receptor point in the area. The coefficient of variance is the standard deviation of the data divided by the arithmetic mean. As expected for concentrations that are not normally distributed, the coefficient of variance is very high indicating that the arithmetic mean and standard deviation are very inefficient estimators for the frequency distributions observed in the study area.

The geometric standard deviations (GSD, labeled geometric coefficient of variance) are mapped in Figures 13 a and 13b. Occurrences of high values of the GSD are noted on the edges of the study area at (3484, 5550) and (3480, 5549). High values for the second-high concentration (Figures 14a and 14b) based on the delta function are also noted for these areas. A study of the concentrations at these points (not included in this paper) shows a high incidence of zero concentrations. The Kolmogorov-Smirnov tests were passed by these points, but GSD values greater than 5 lead one to suspect that the effect of many zero concentrations which are effectively ignored by the delta-lognormal distribution has distorted the calculated parameters. The effect of such distortions in the data is not evident in the remaining maps for the Larsen Lognormal second-high value (Figures 15a and 15b) and the various percentile plots (Figures 9, 10 and 11) discussed earlier.

Summary

The TCM and TEM/FRED generally agree in the calculation of the arithmetic mean (Figures 4 and 7). Values of the geometric mean, geometric standard deviation and various percentile concentrations are credibly produced by FRED for the receptor points that passed the Kolmogorov-Smirnov tests for lognormality. At seventy-three of the two hundred forty-two receptor grid points the test for lognormality failed. All but two of the receptors that failed were located in areas that are either not densely populated or located on the edge of a built up area. A better representation of the frequency distributions of concentrations would be possible if seasonal climatology were available as an input to FRED.

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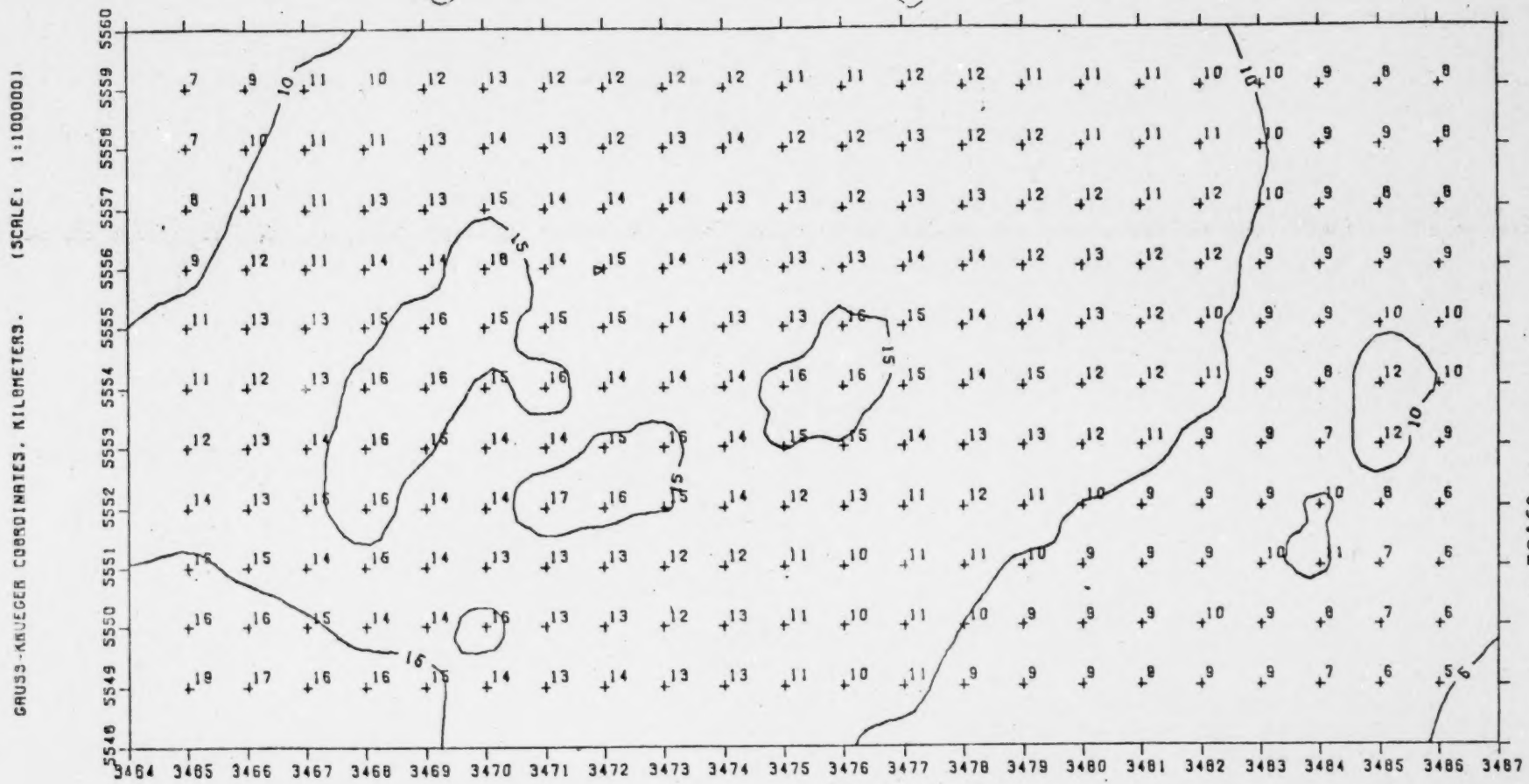
FIGURES

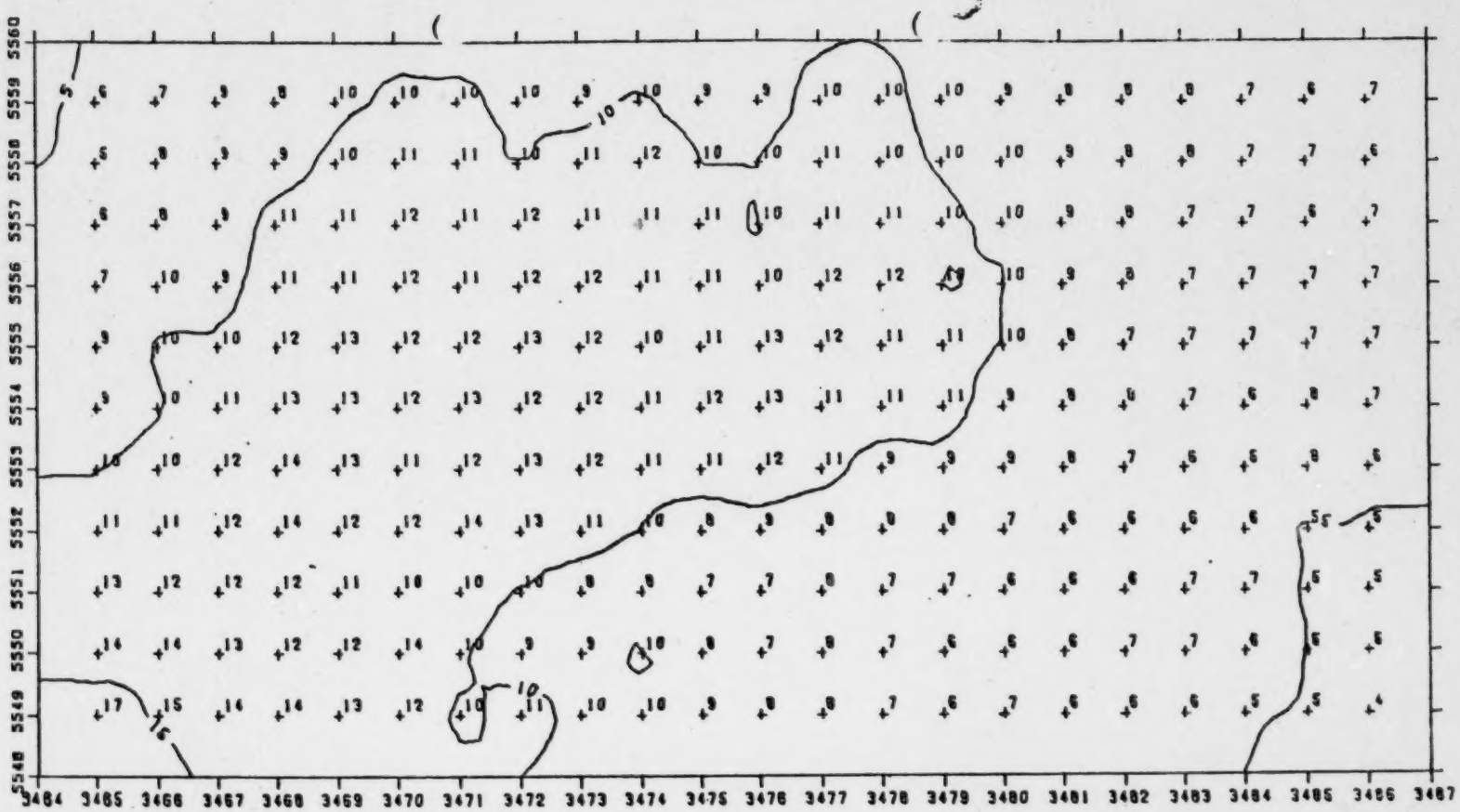
2 - 15



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TCM: POINT SOURCES WITH EMISSION RATES OVER 0.1 G/S ONLY.

CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

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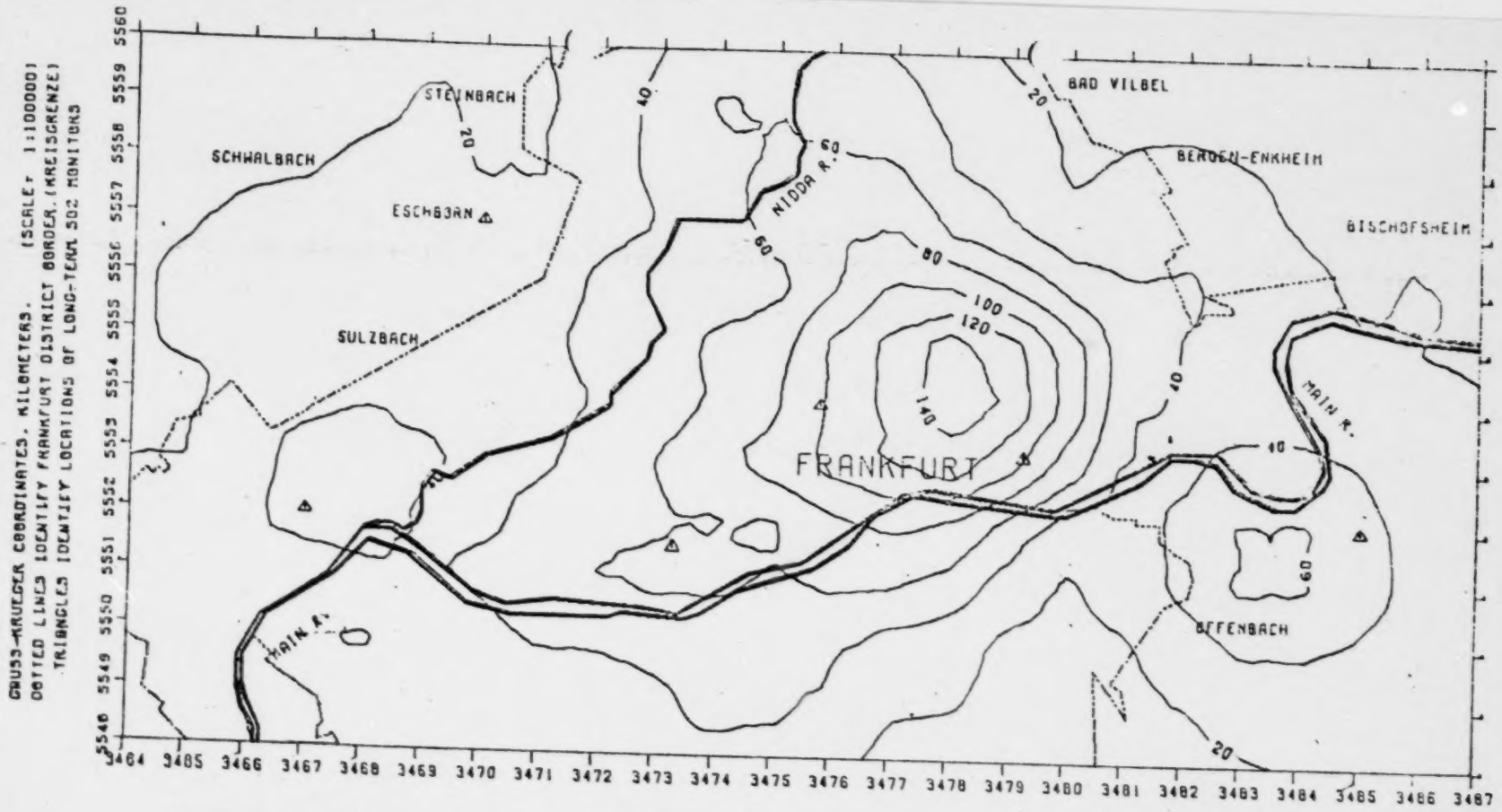
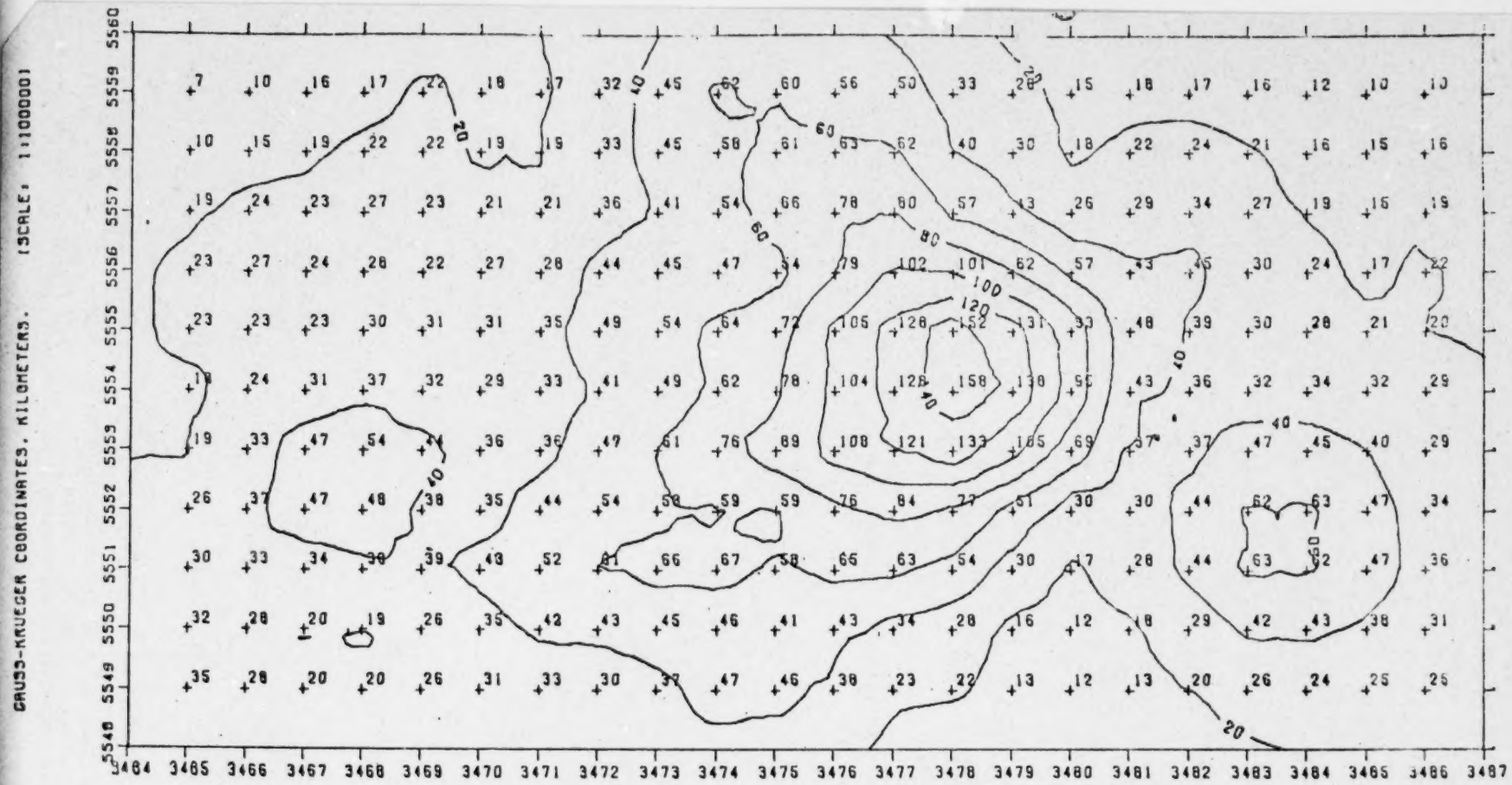


FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TCM: F=50, AREA EMISSION RADIUS = 1.5 KM

CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

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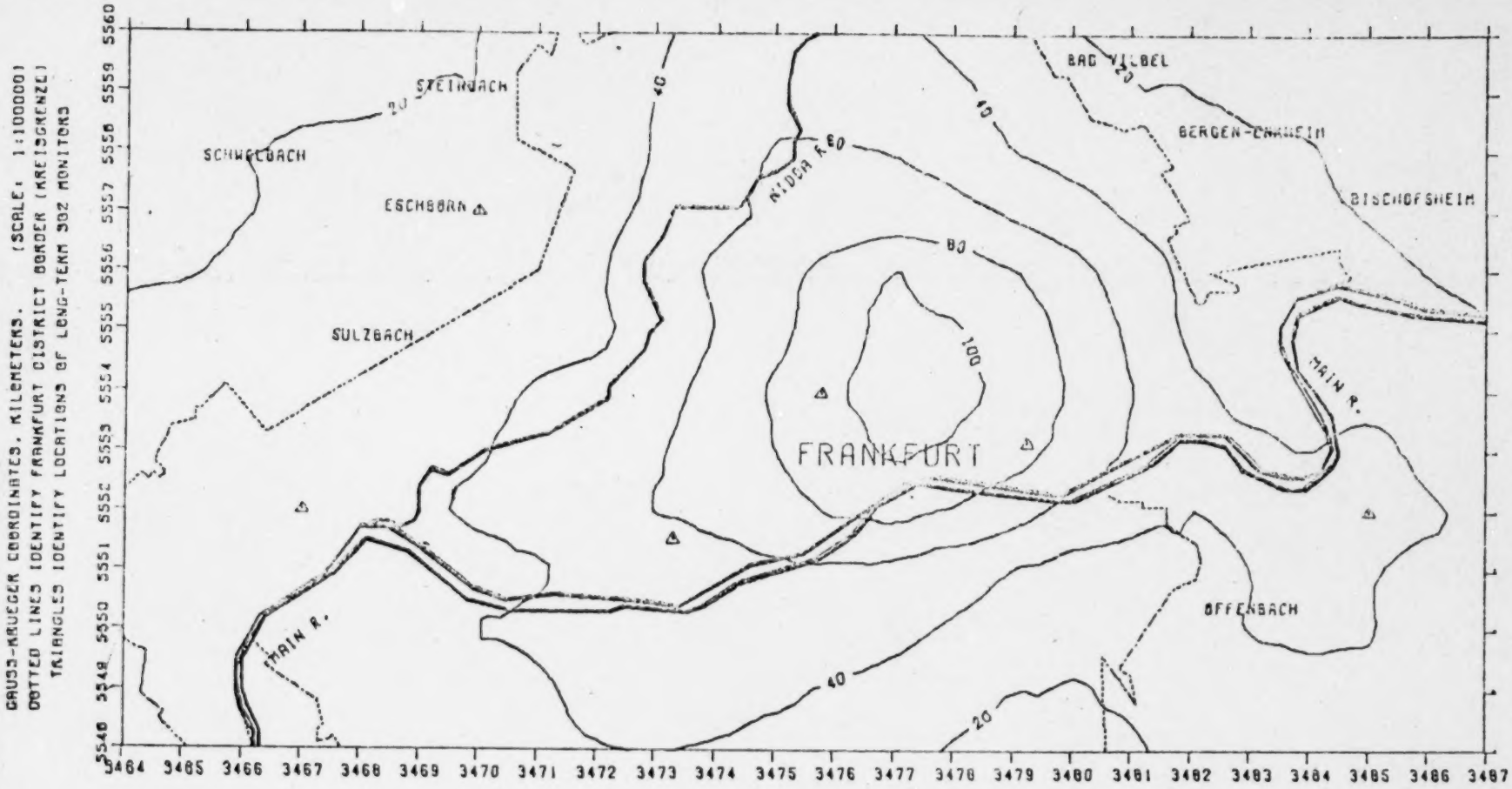
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

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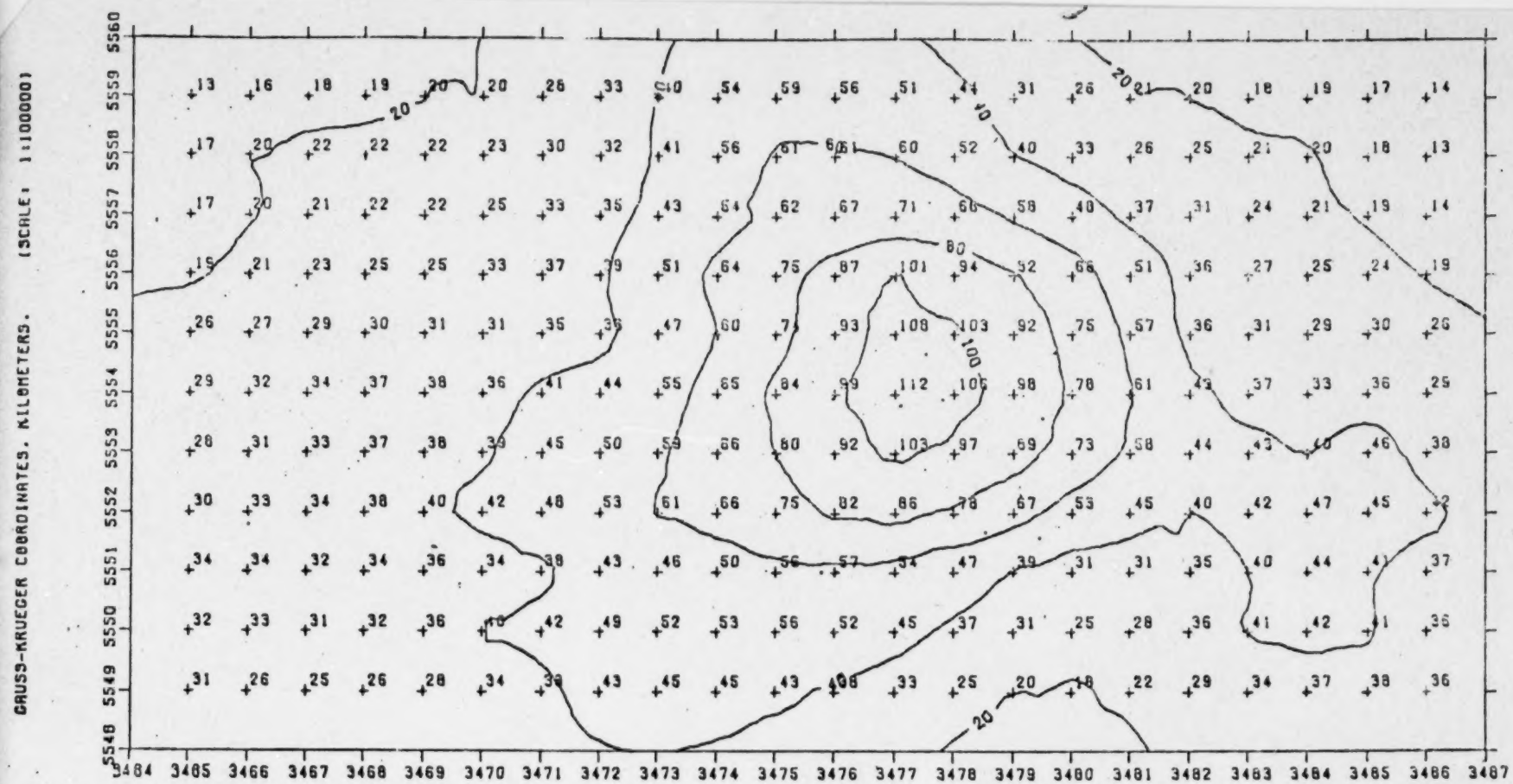
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

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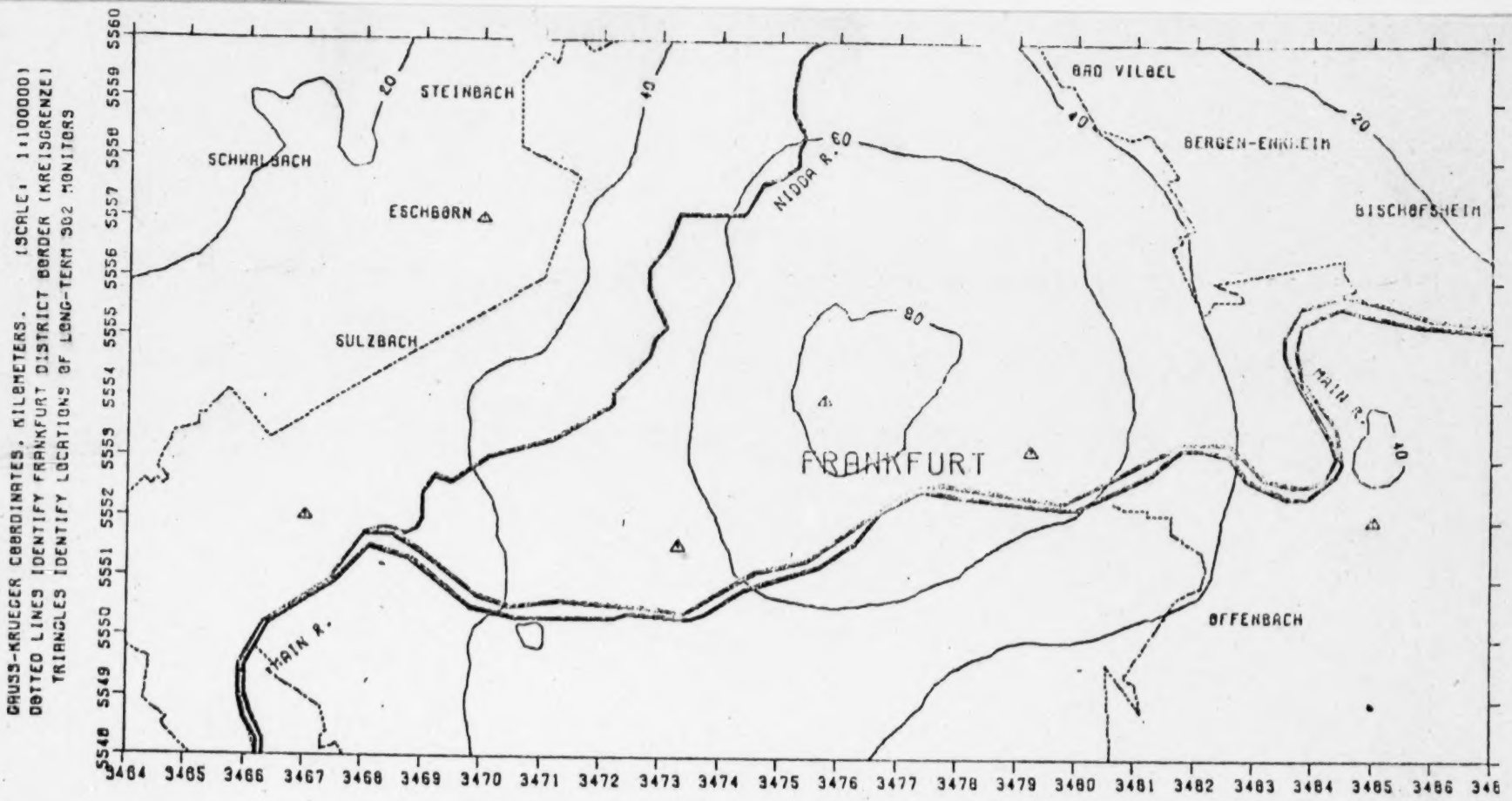
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

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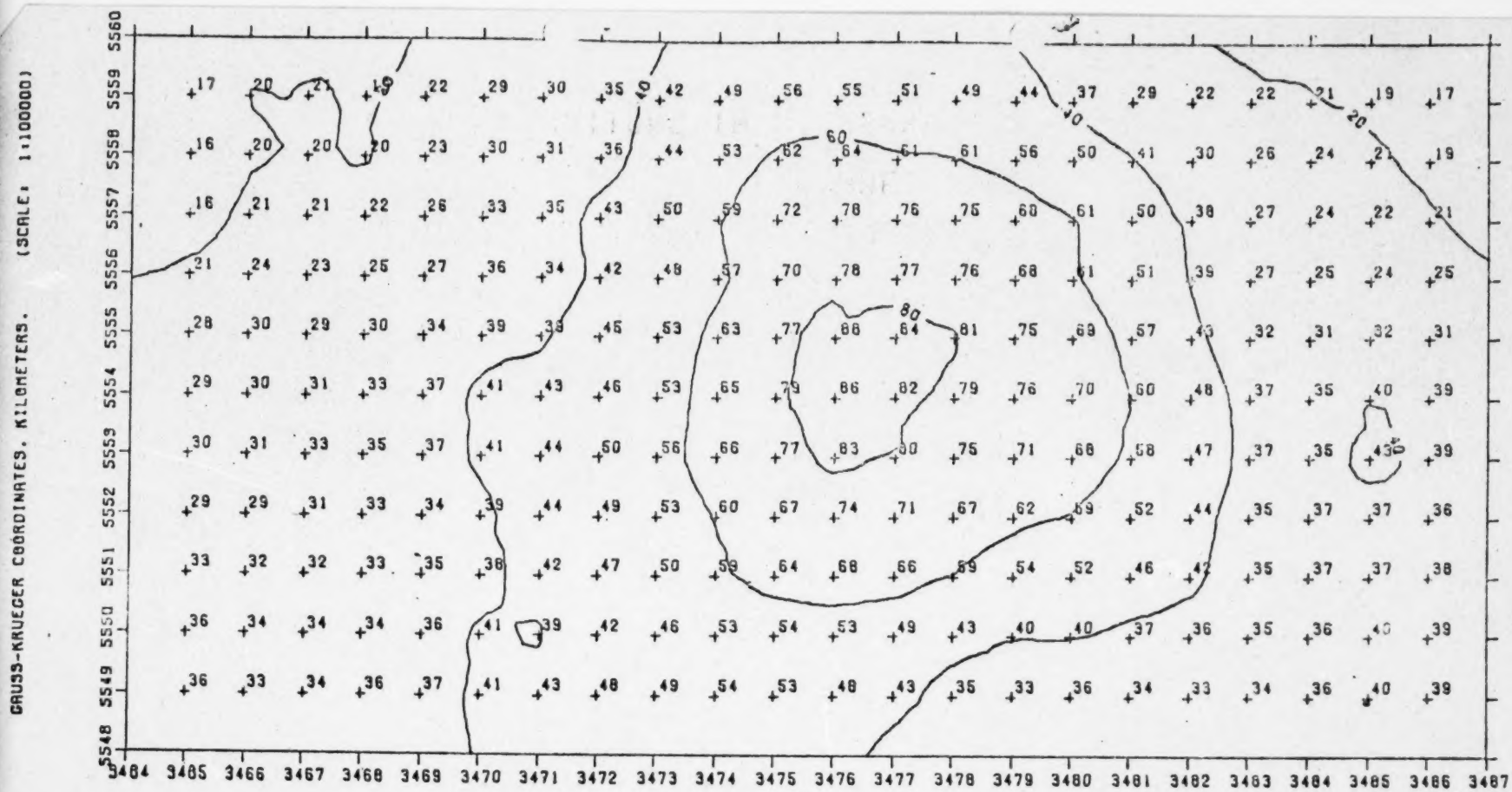
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

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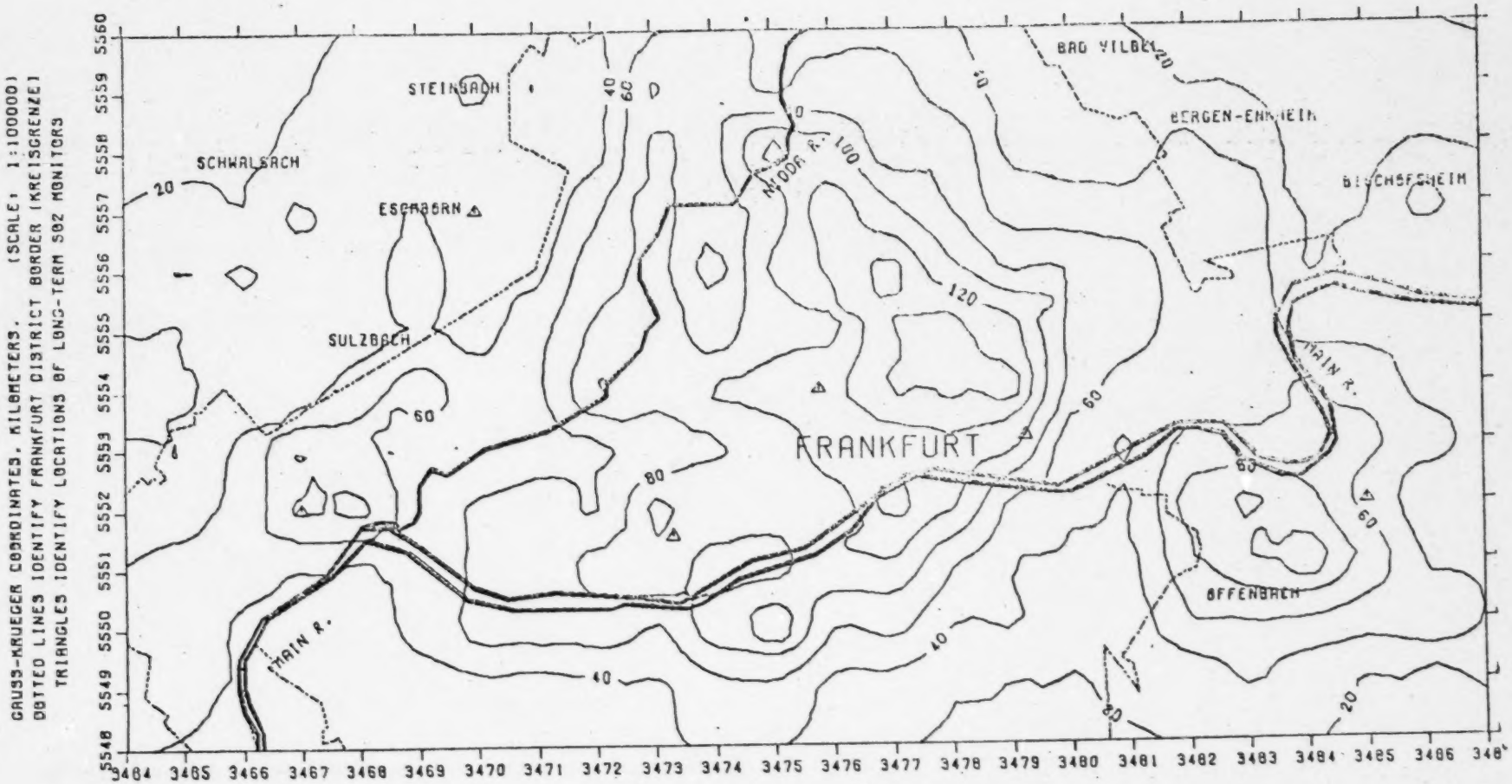
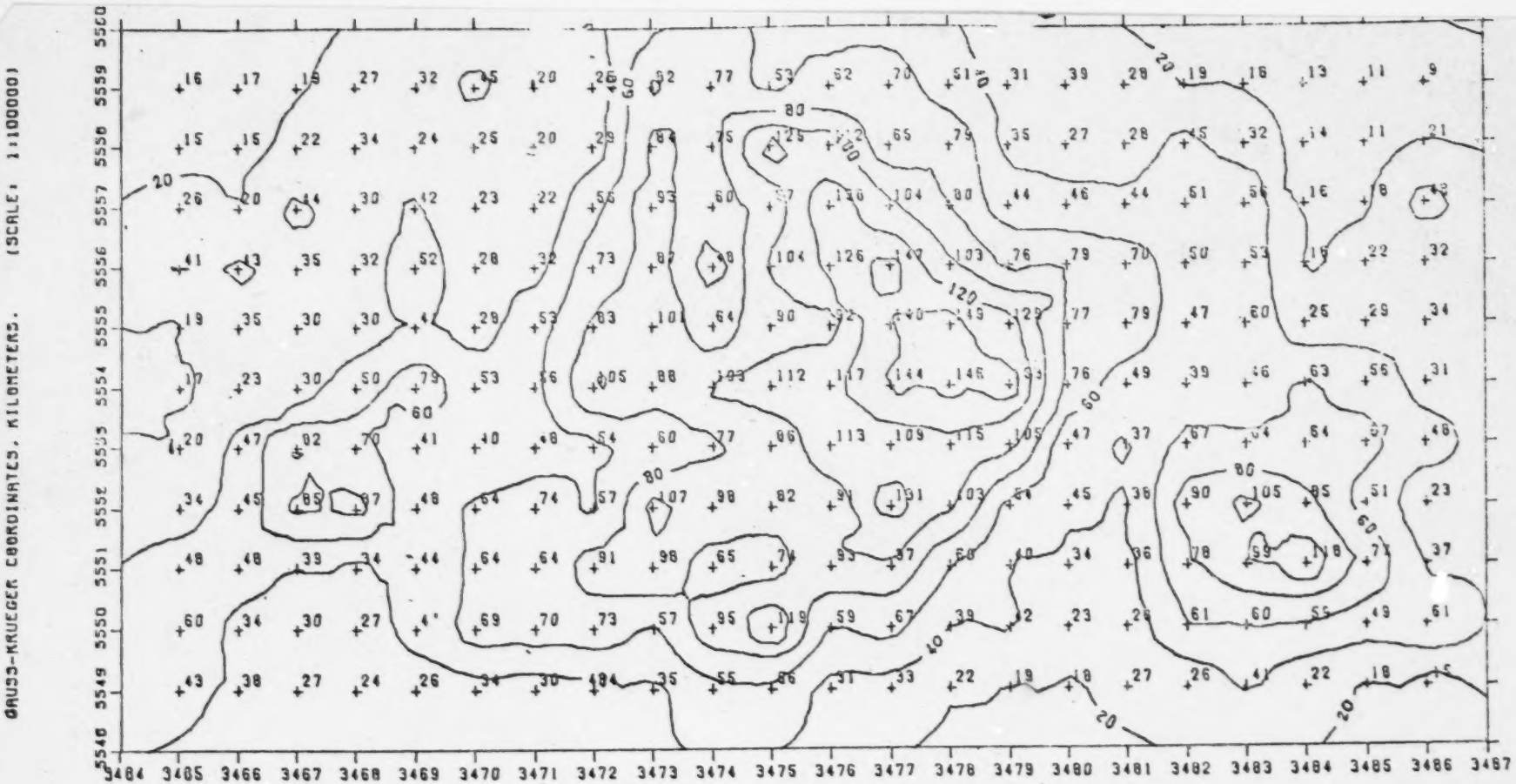
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: ARITHMETIC MEAN

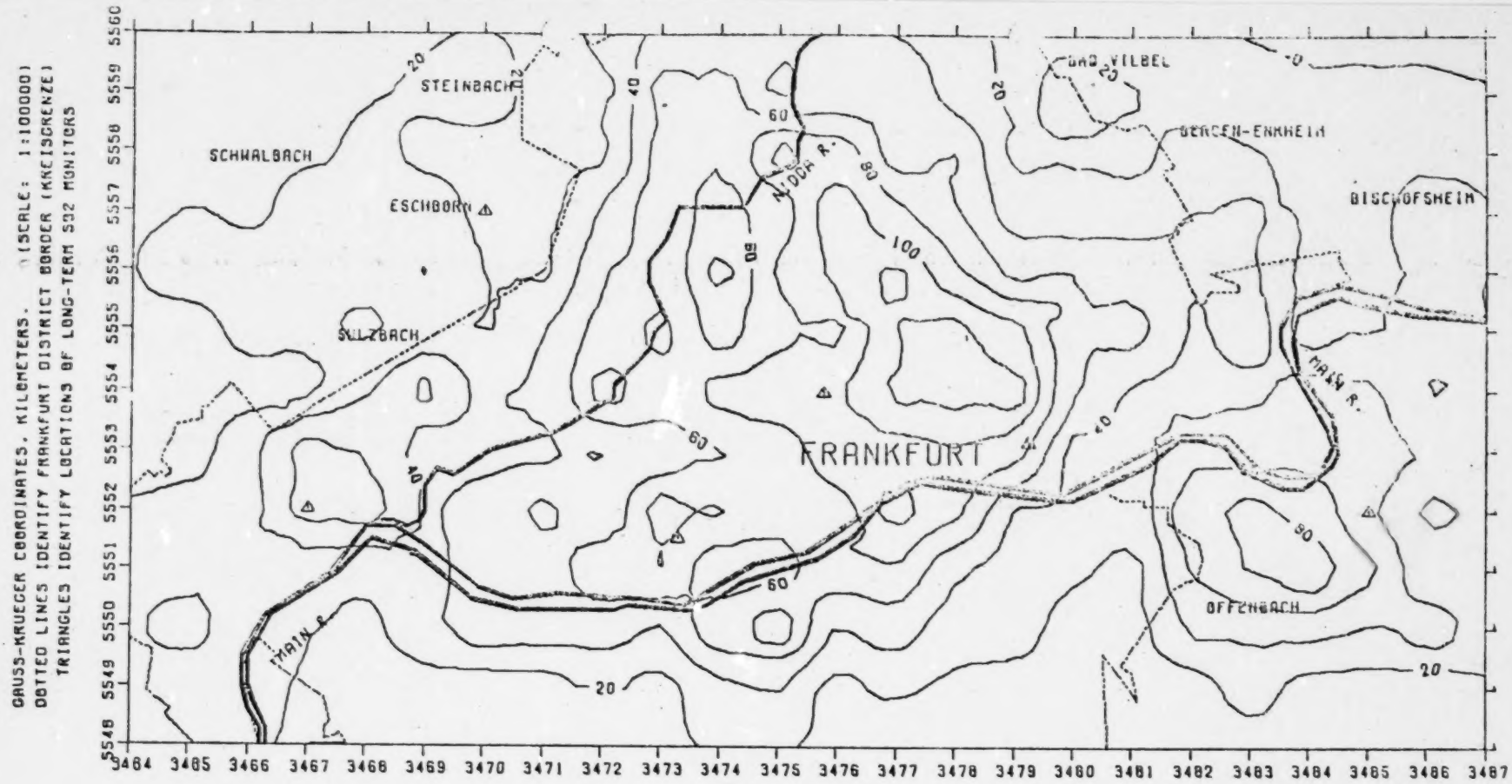
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: ARITHMETIC MEAN

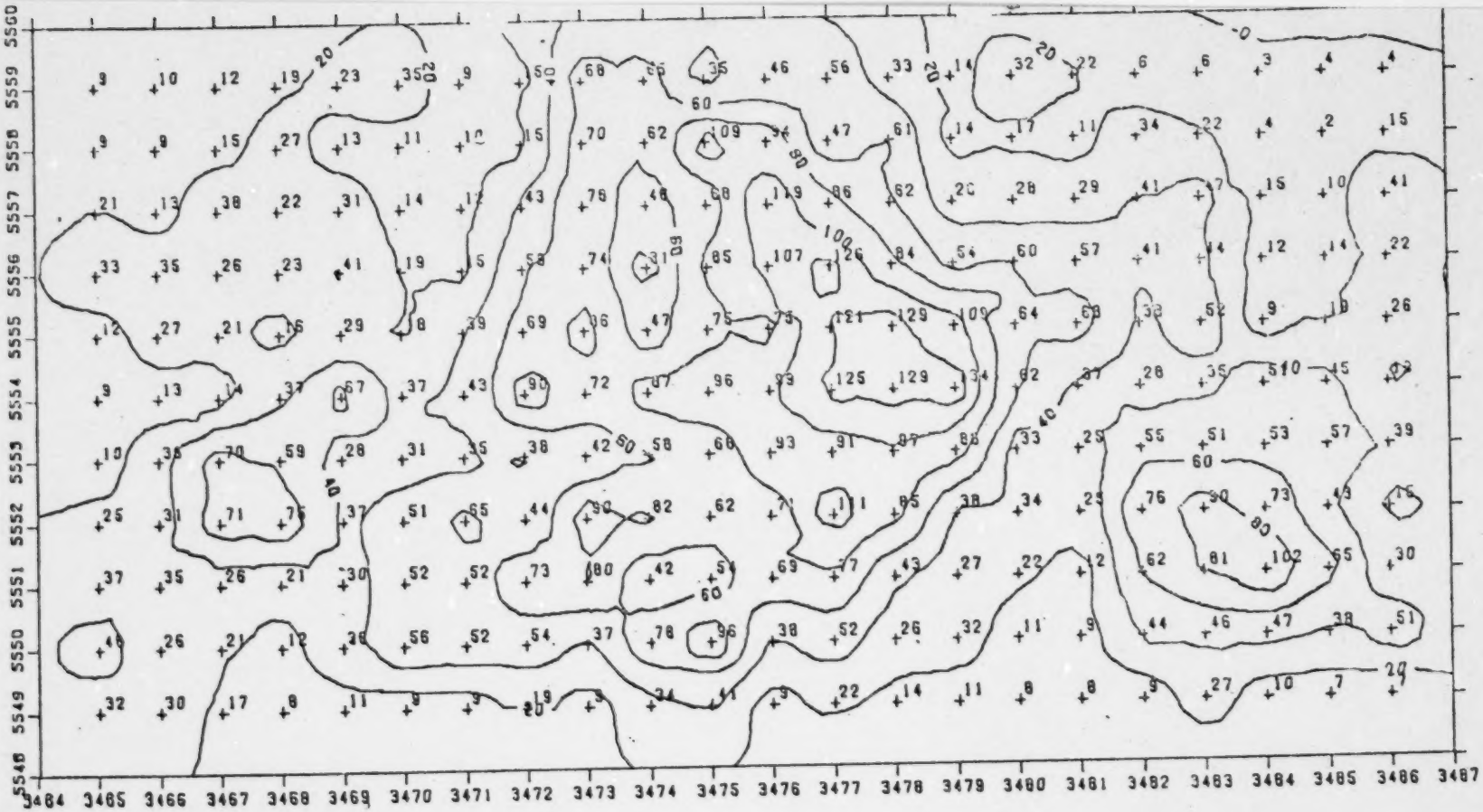
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: GEOMETRIC MEAN

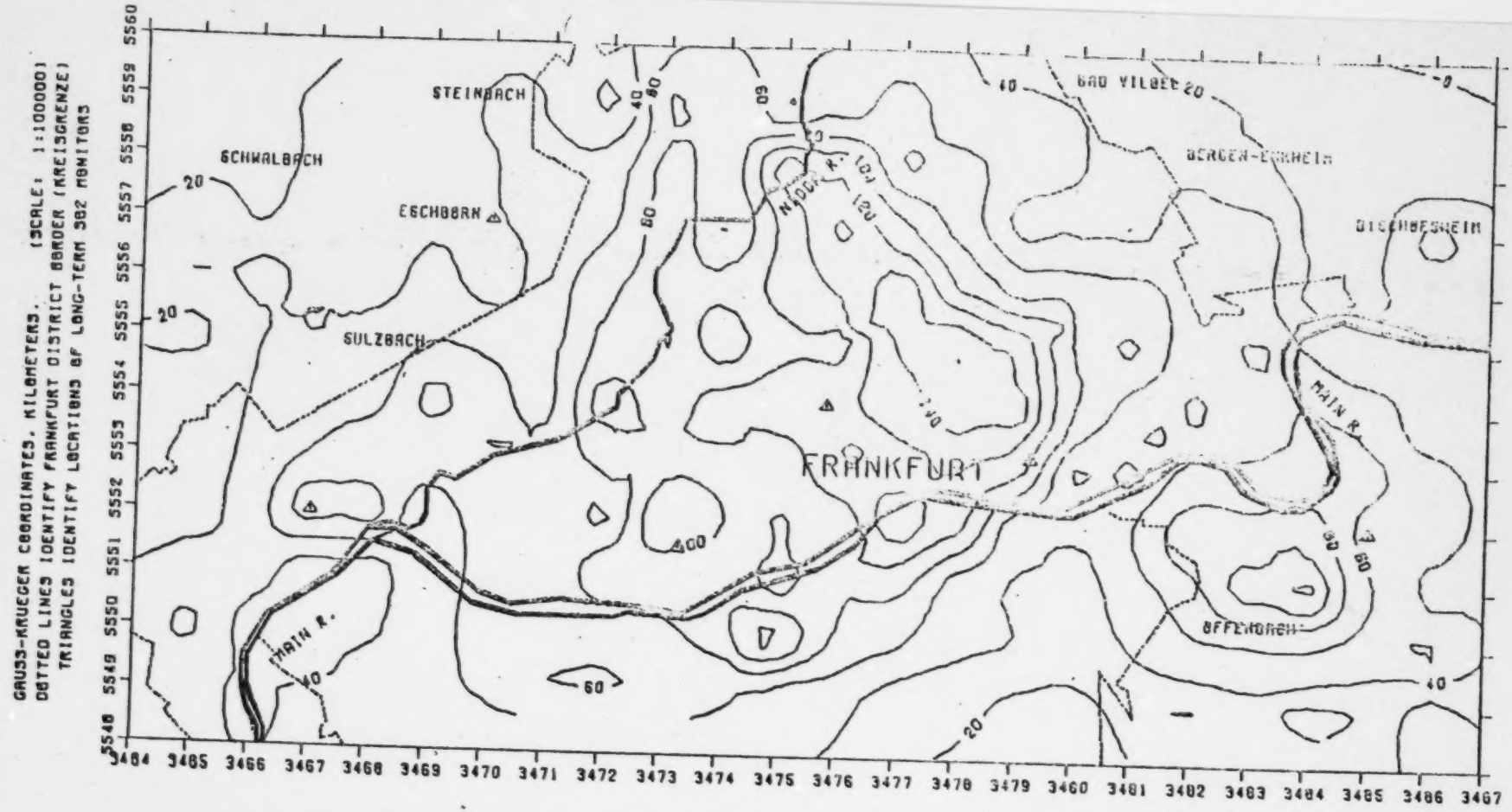
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: GEOMETRIC MEAN

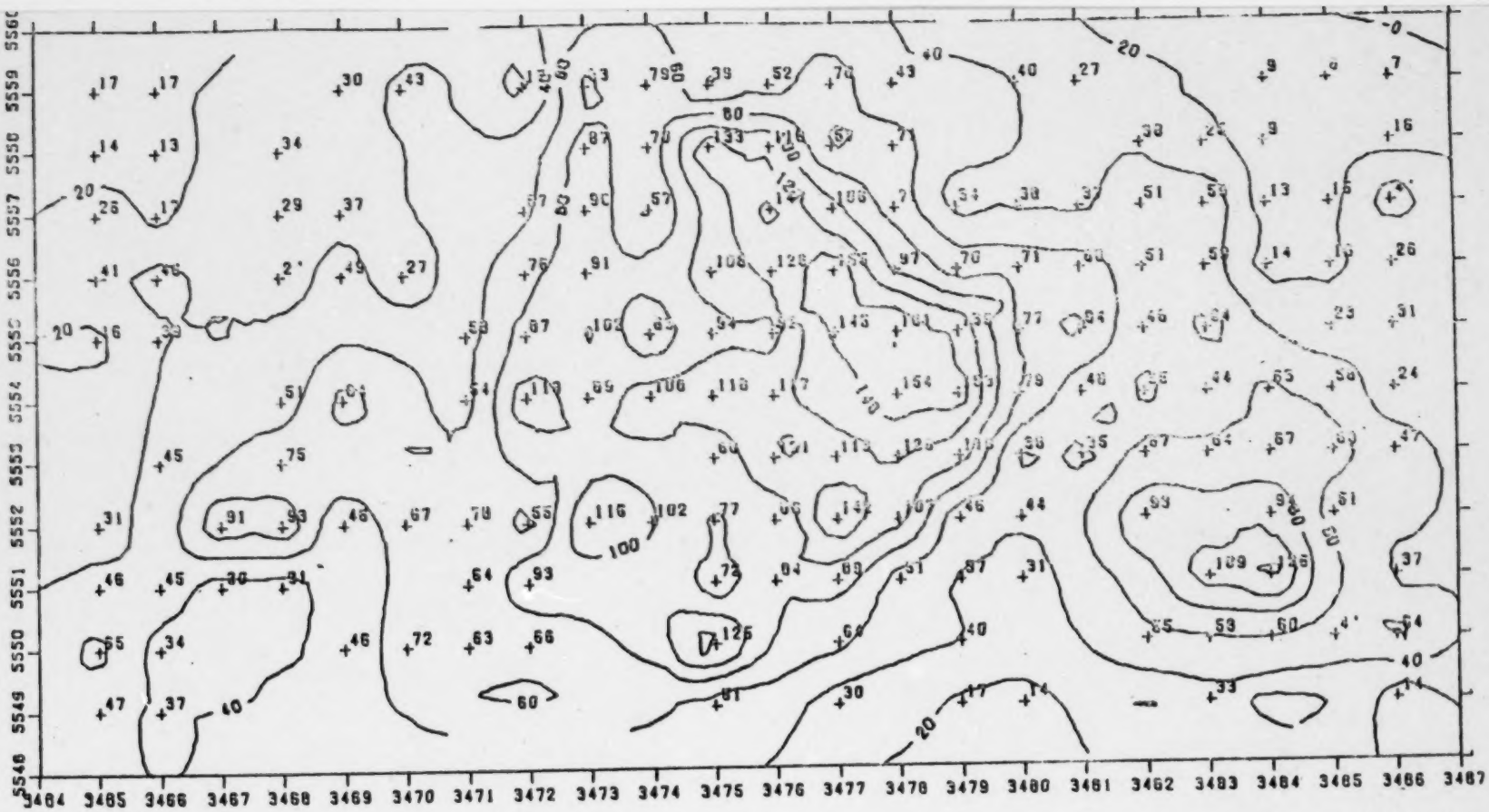
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: VALUE AT CUMULATIVE FREQUENCY OF 60.0 PERCENT

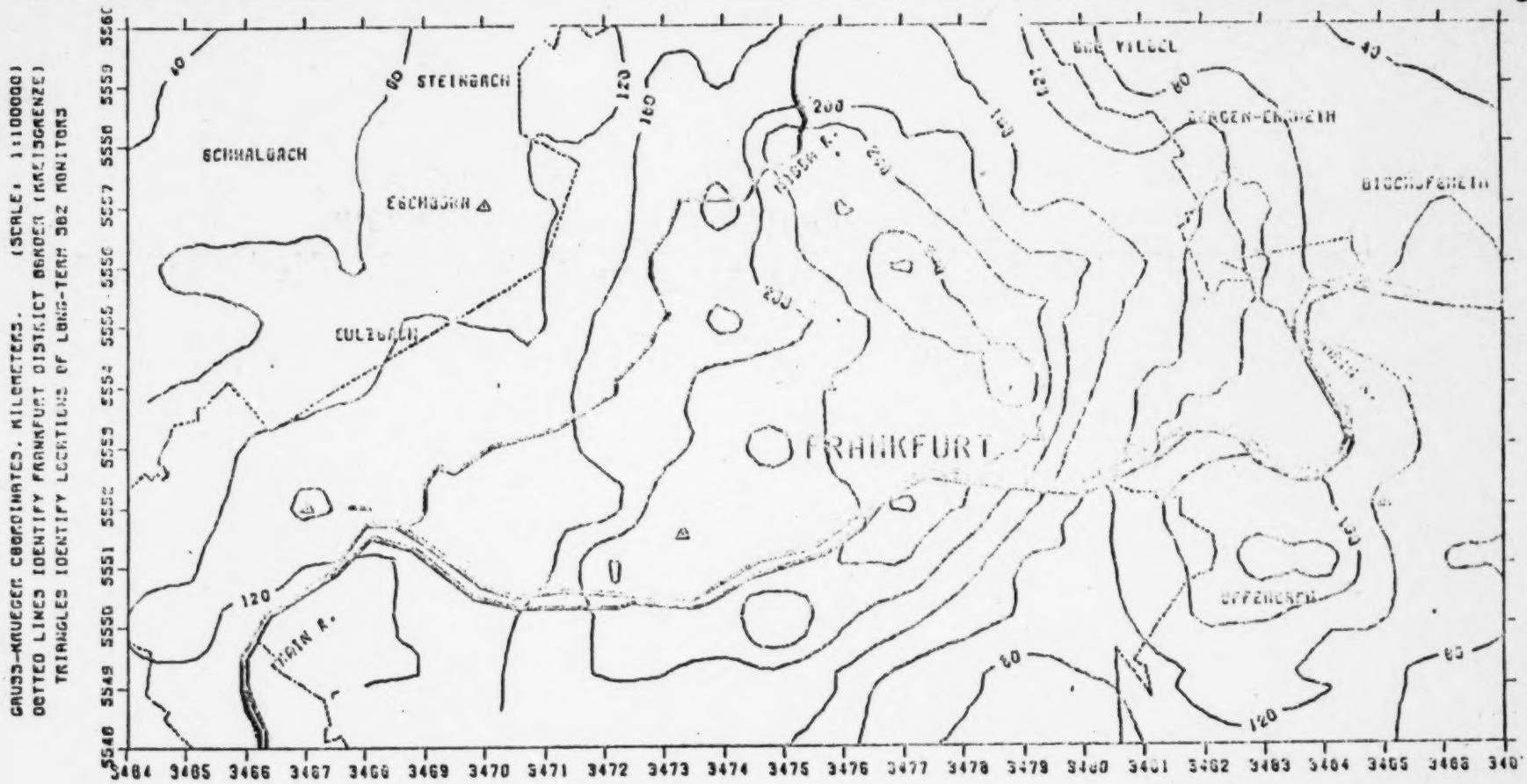
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: VALUE AT CUMULATIVE FREQUENCY OF 60.0 PERCENT

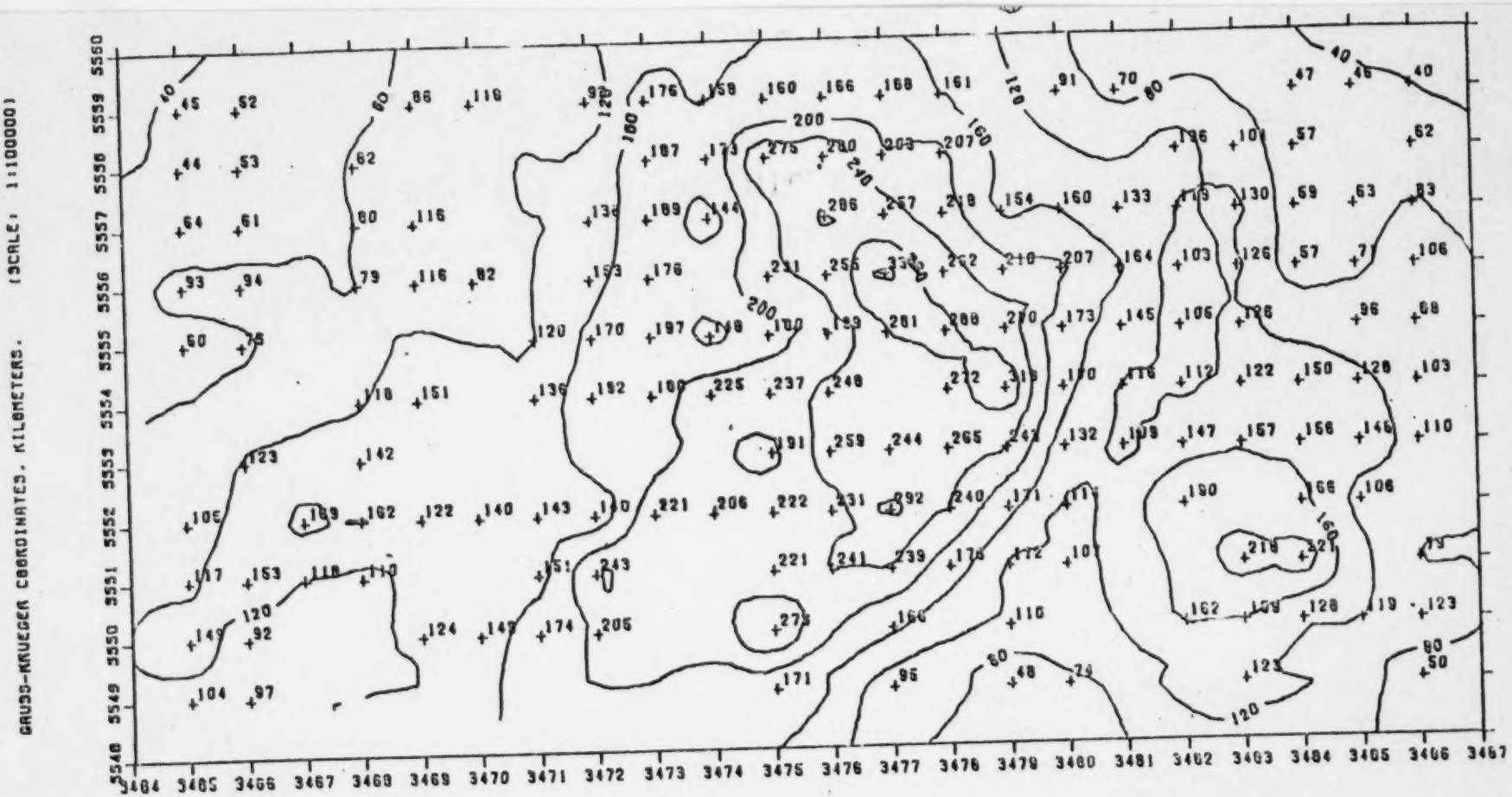
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: VALUE AT CUMULATIVE FREQUENCY OF 95.0 PERCENT

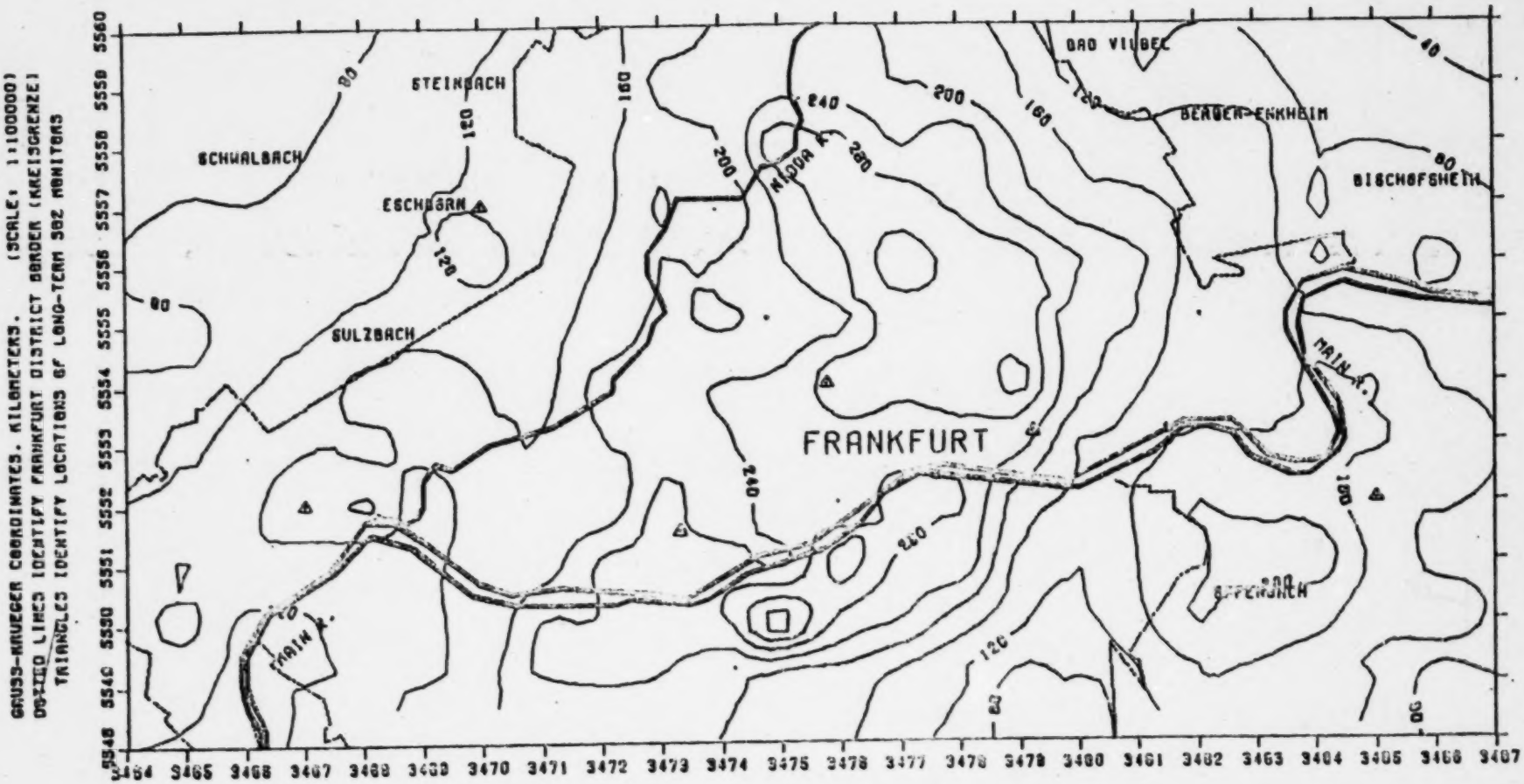
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: VALUE AT CUMULATIVE FREQUENCY OF 95.0 PERCENT

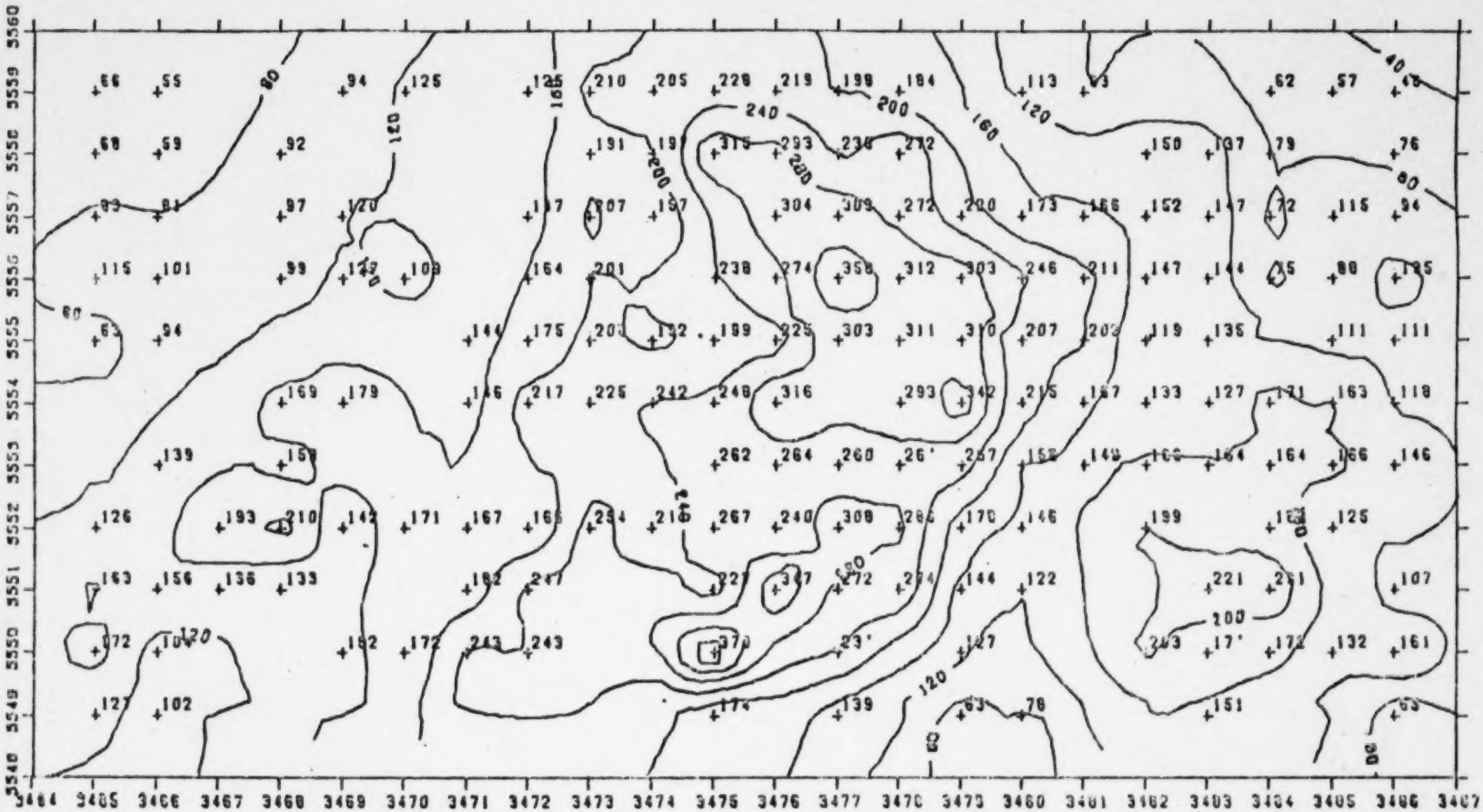
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: VALUE AT CUMULATIVE FREQUENCY OF 97.5 PERCENT

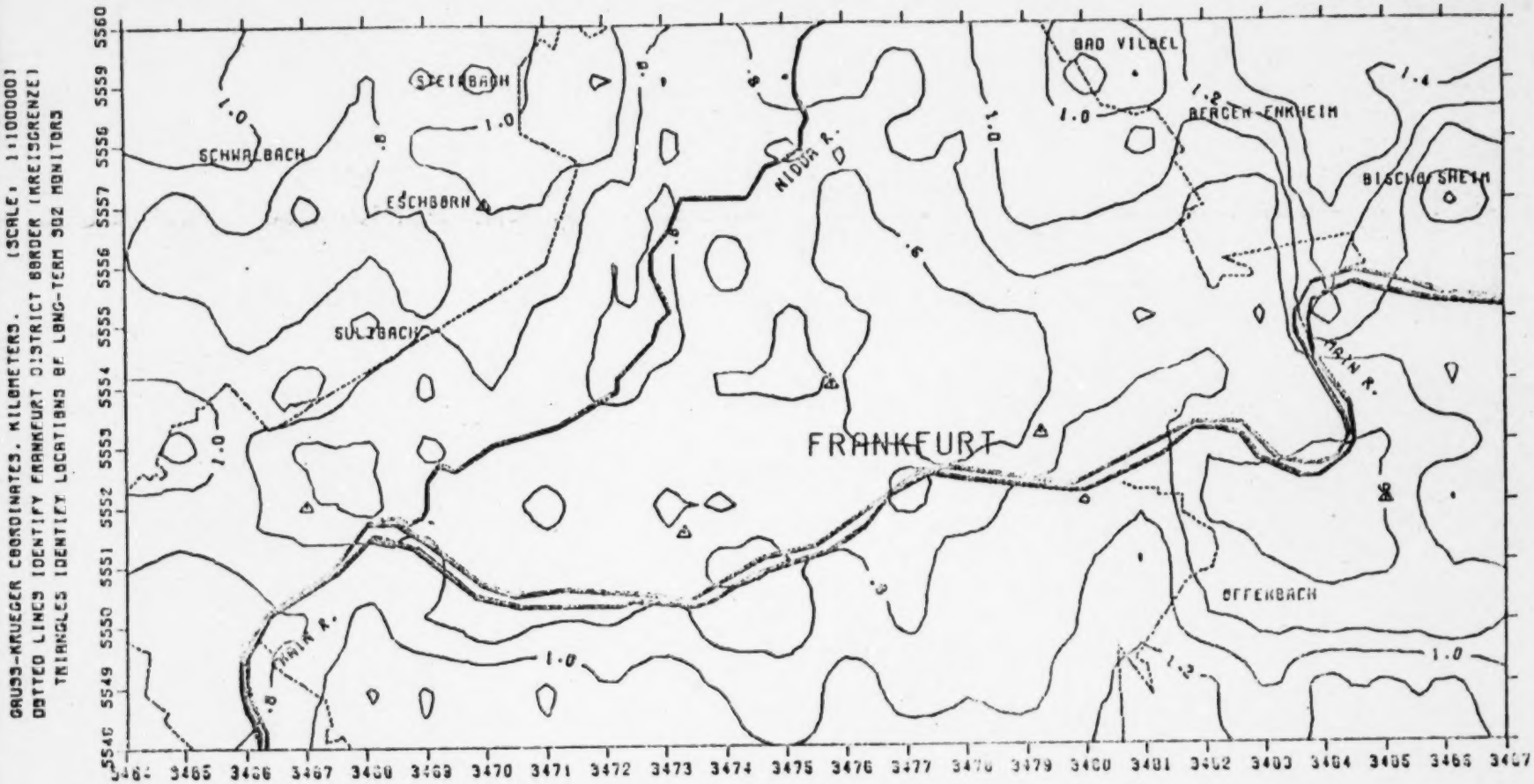
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: VALUE AT CUMULATIVE FREQUENCY OF 97.5 PERCENT

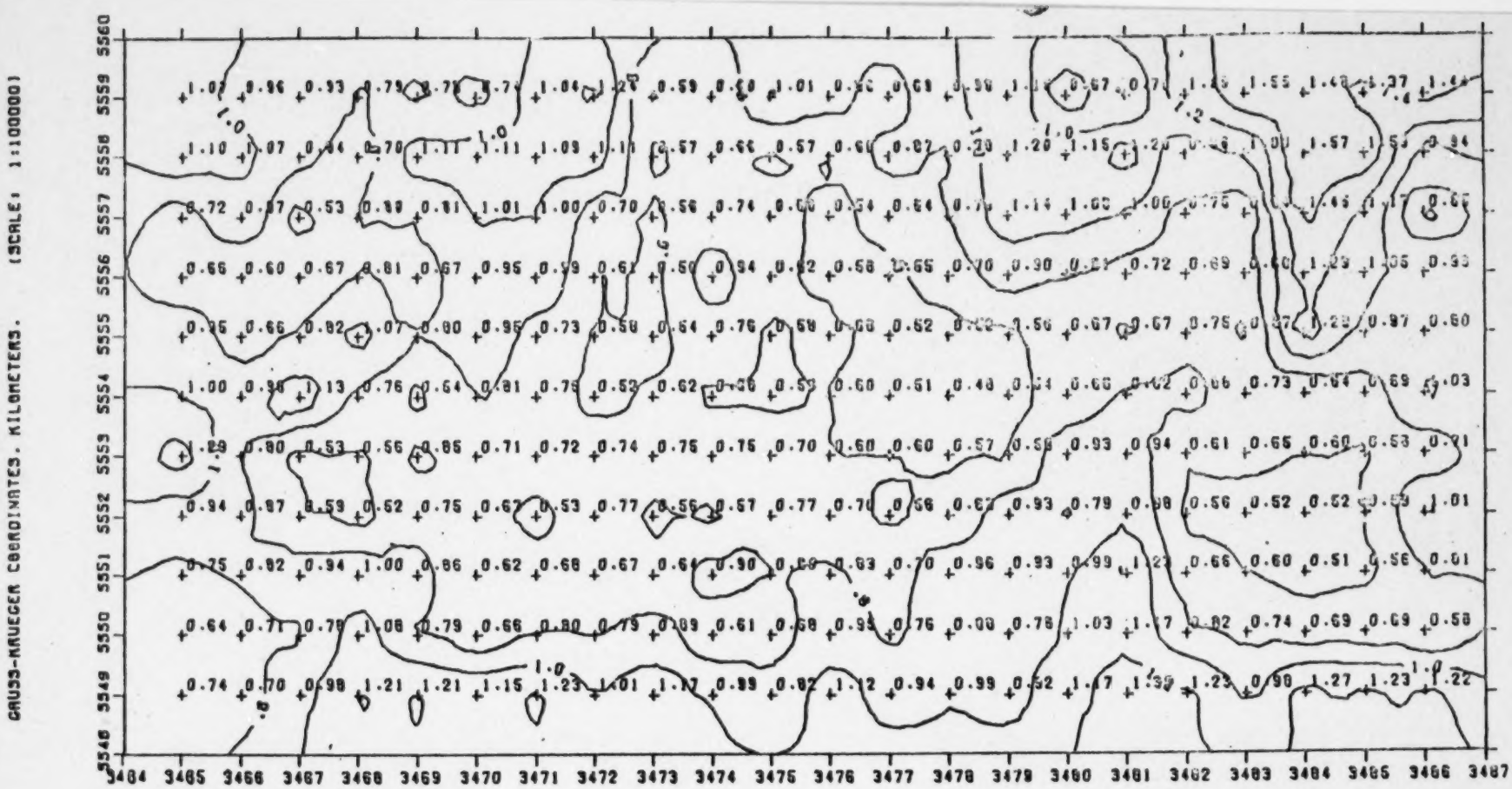
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: COEFFICIENT OF VARIANCE

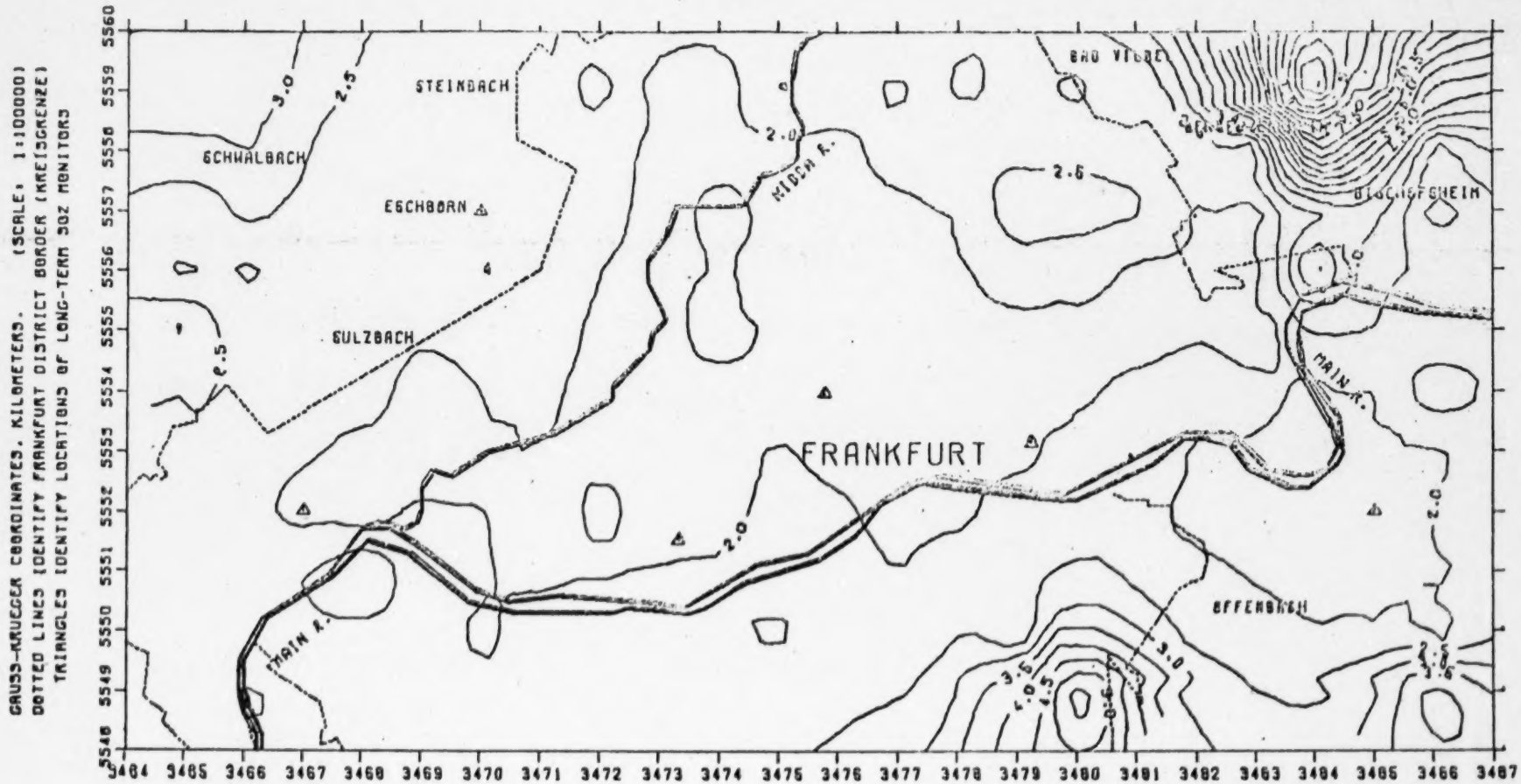
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: COEFFICIENT OF VARIANCE

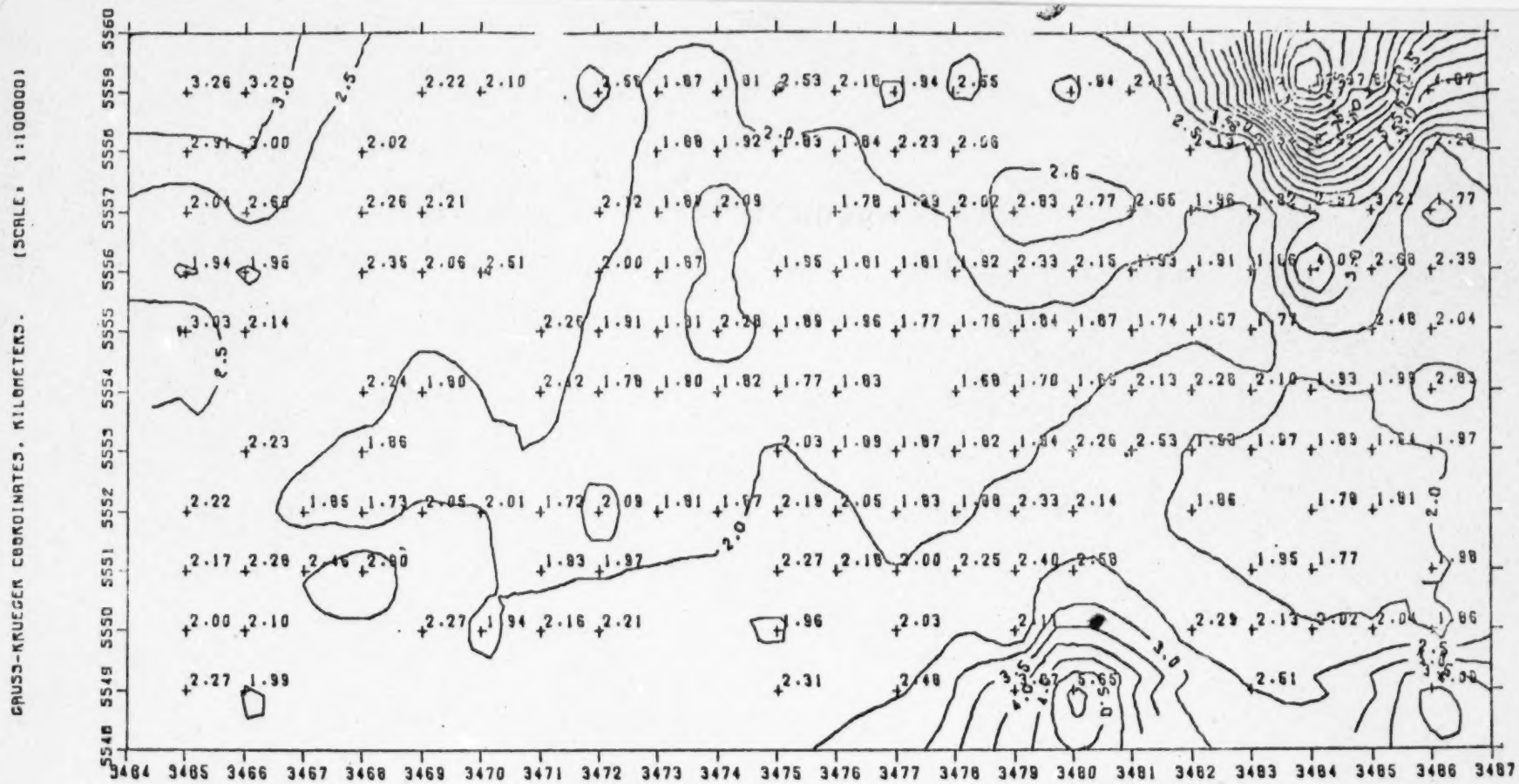
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: GEOMETRIC COEFFICIENT OF VARIANCE

CONCENTRATIONS IN MICROGRAMS PER CUBIC METER

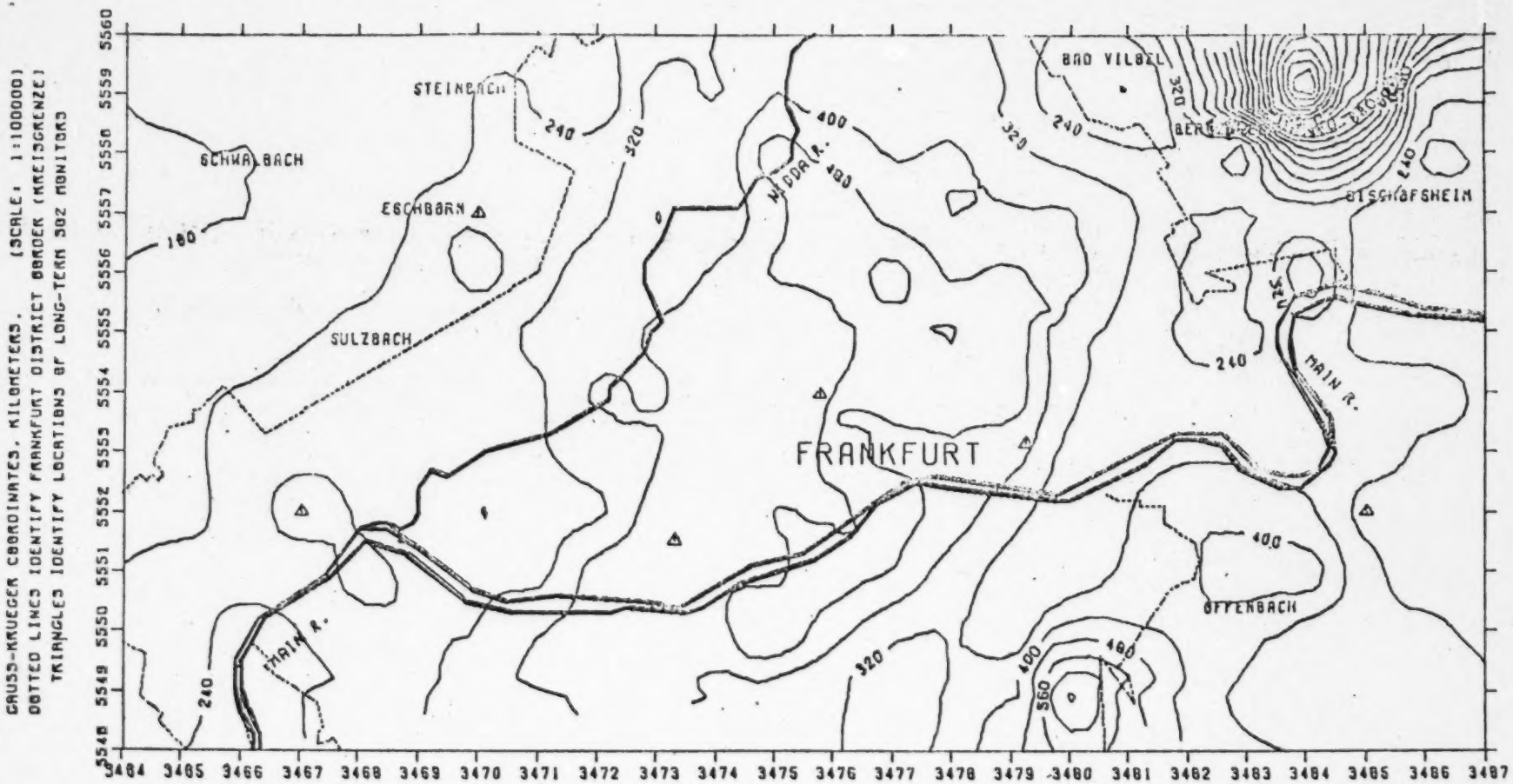


FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: GEOMETRIC COEFFICIENT OF VARIANCE

CONCENTRATIONS IN MICROGRAMS PER CUBIC METER

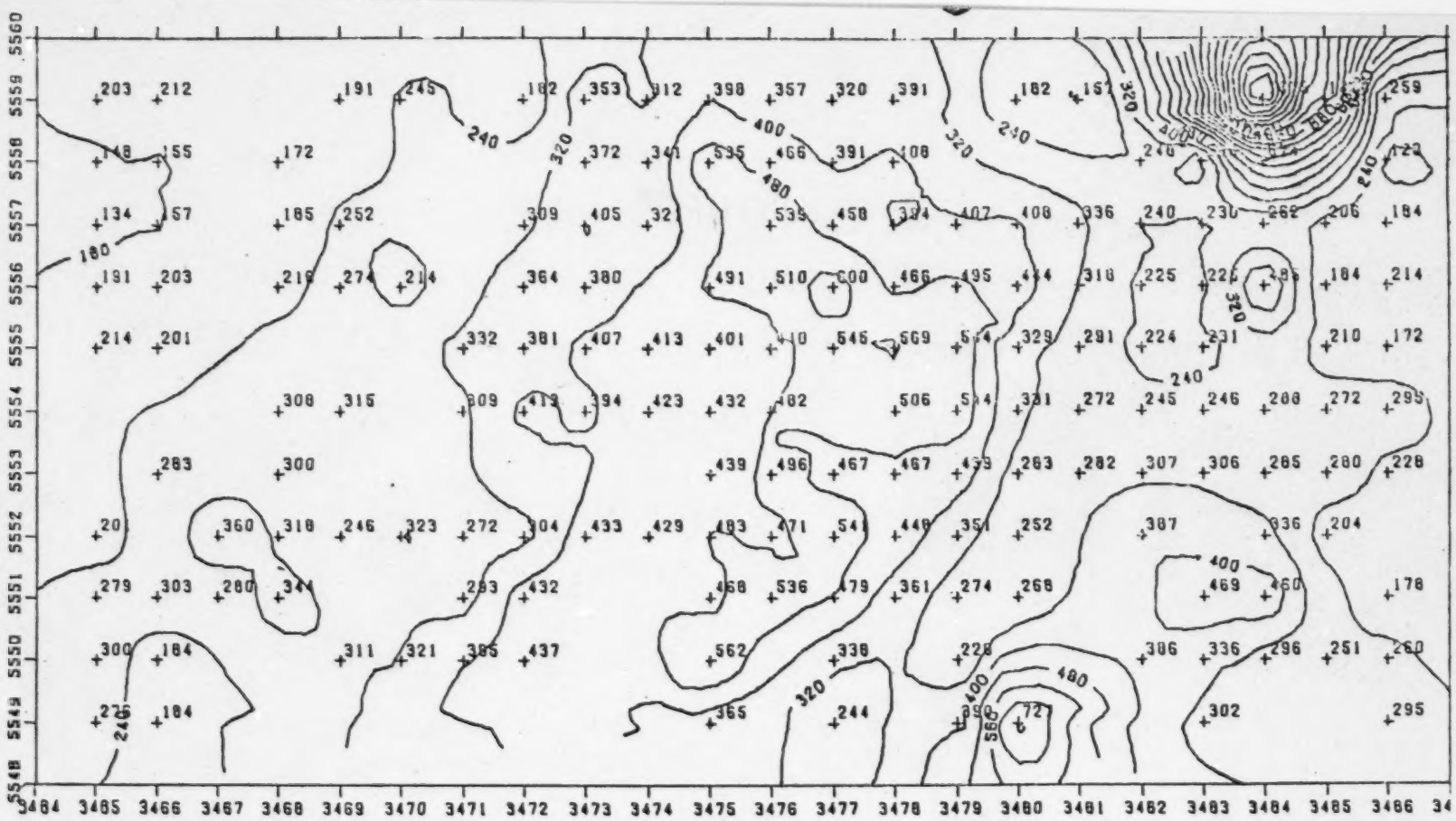
- 69.53 -



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: 2ND-HIGH 24 HR. VALUE FROM DIRECT LOGNORMAL FIT TO DATA

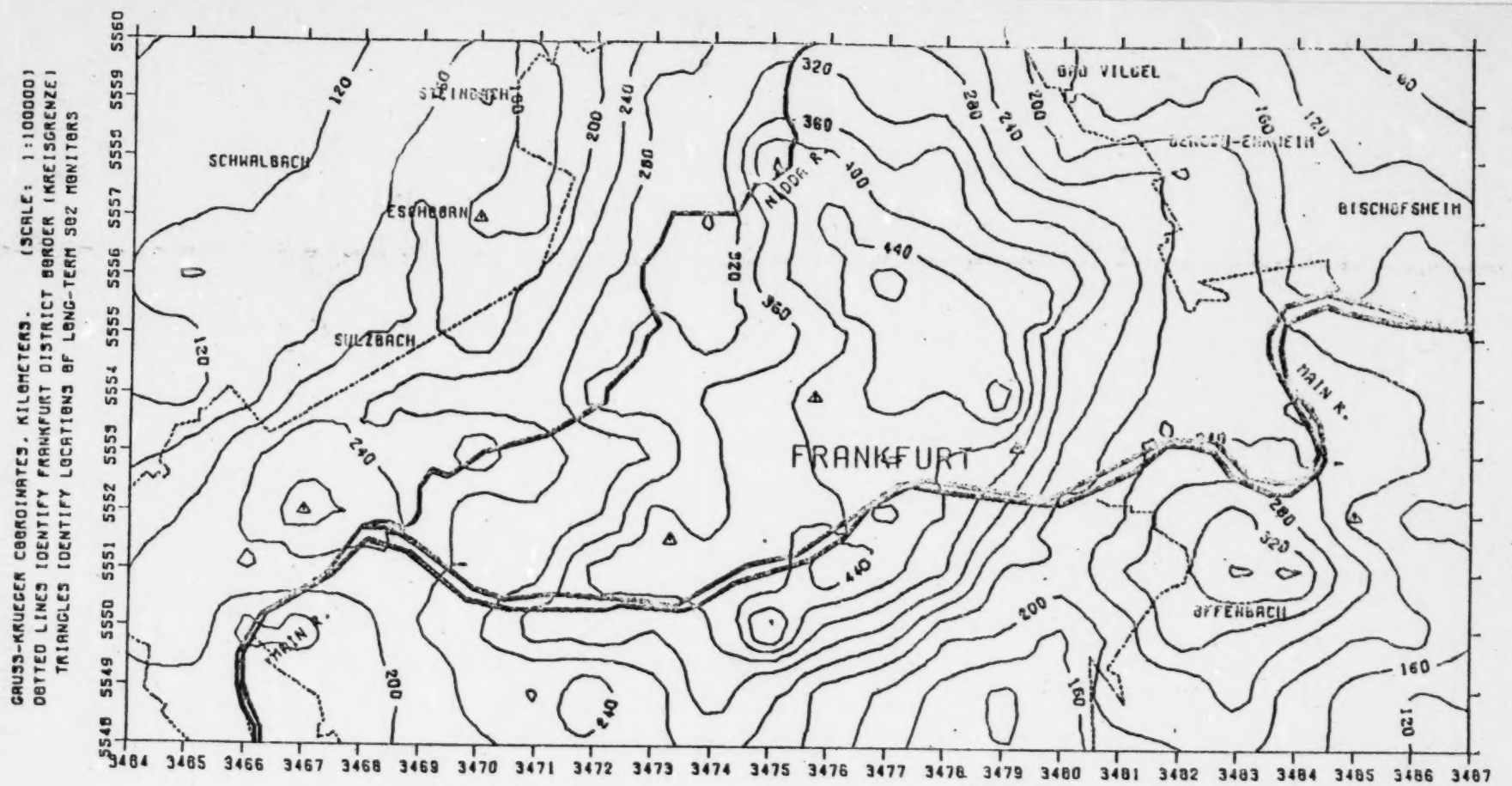
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: 2ND-HIGH 24 HR. VALUE FROM DIRECT LOGNORMAL FIT TO DATA

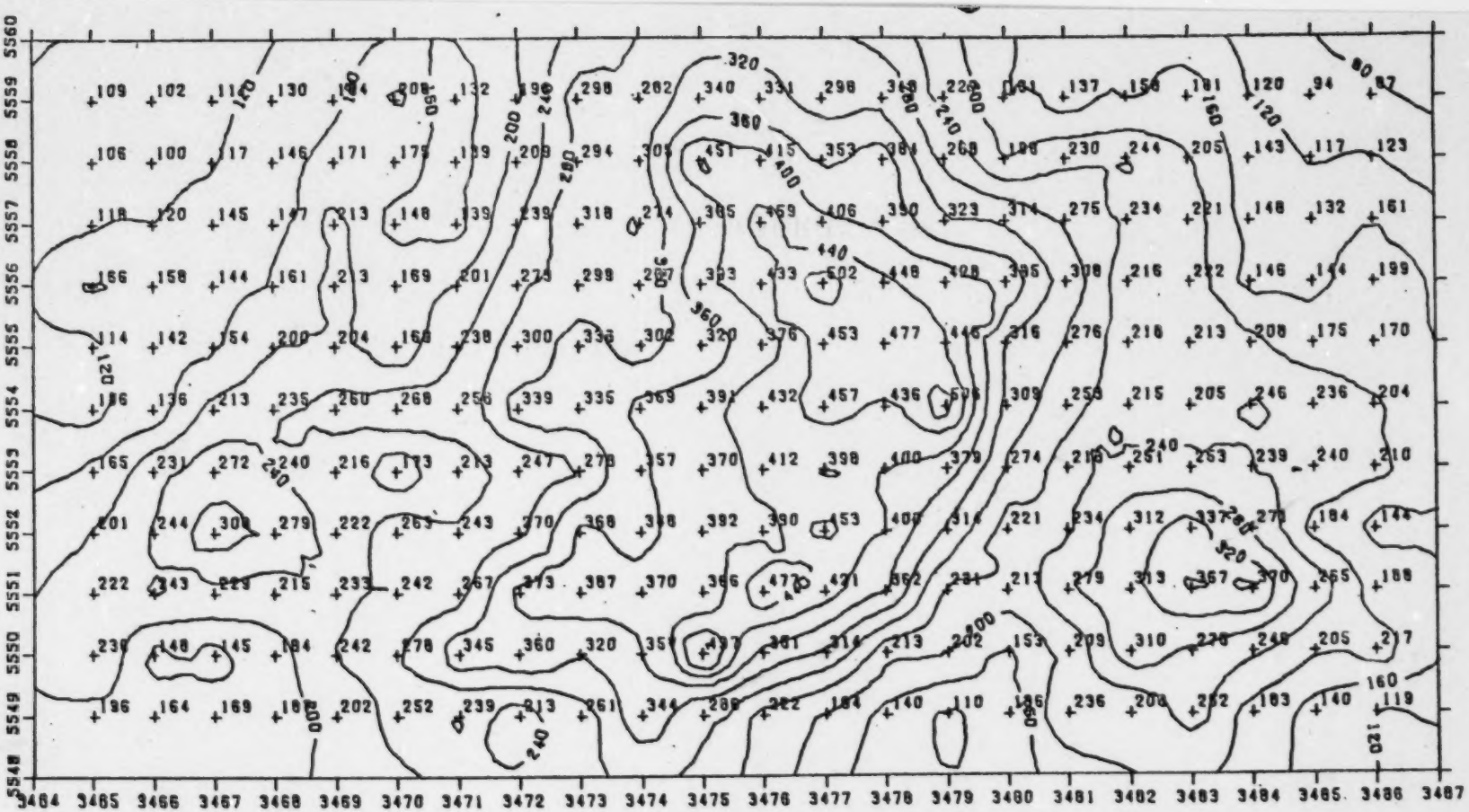
CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: 2ND-HIGH 24 HR. VALUE FROM LARSEN LOGNORMAL FIT TO DATA

CONCENTRATIONS IN MICROGRAMS PER CUBIC METER



FRANKFURT AM MAIN - PREDICTIONS OF ANNUAL SO2 CONCENTRATIONS

TEM: 2ND-HIGH 24 HR. VALUE FROM LARSEN LOGNORMAL FIT TO DATA

CONCENTRATIONS IN MICROGRAMS PER CUBIC METER

- 69.57 -

APPENDIX A

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N

NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

LOGICAL UNIT NUMBERS FOR READING PREDICTED CONCENTRATION FILES: 11 12 13 14 15 16. LOGICAL UNIT NUMBER FOR CARD-IMAGE OUTPUT: 1.

NUMBER OF SCENARIOS FOR EACH MODEL RUN: 2 3 5 6 0 3. THIS RUN PROCESSES RECEPTORS 1 TO 6/ 6 RECEPTORS TO INTERPOLATE.

22 COLUMNS AND 11 ROWS IN RECEPTOR GRID. COORDINATES OF SOUTHWEST CORNER OF GRID: X=3464.50 KM, Y=5546.50 KM. SPACING= 1.0000 KM.

TYPES OF OUTPUT TO BE PRODUCED BY THIS RUN:

ARITHMETIC AND GEOMETRIC MEANS AND STANDARD DEVIATIONS, EXPECTED 2ND HIGHEST 24 HOUR CONCENTRATION
PARAMETERS OF LOGNORMAL DELTA-DISTRIBUTION FITTED TO CONCENTRATION DATA
CONCENTRATION DATA GROUPED AND DISPLAYED IN A HISTOGRAM, GROUPING OPTION 1
CUMULATIVE FREQUENCY DISTRIBUTION(S)
CARD-IMAGE OUTPUT FOR PLOTTING

LOWER LIMIT OF FIRST GROUP = .00, GROUP WIDTH = 8.00 CUMULATIVE FREQUENCY LEVELS (PERCENT) FOR PLOTTING: 60.0, 95.0, 97.5.

CARD-IMAGE IDENTIFICATION LABEL: FRANKFTO

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N

LOCATIONS OF RECEPTORS TO BE INTERPOLATED IN THE RECEPTOR GRID

NUMBER	X (KM)	Y (KM)
1	3473.29	5551.53
2	3479.25	5553.15
3	3475.76	5553.98
4	3467.00	5552.00
5	3470.00	5557.00
6	3485.00	5552.00

PREDICTED CONCENTRATION FREQUENCY DISTRIBUTION

METEOROLOGICAL JOINT FREQUENCY FUNCTION: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RELATIVE FREQUENCIES OF OCCURRENCE FOR WIND SECTORS 1-16

STABILITY CLASS	WIND SPEED CLASS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1	.00000	.00000	.00000	.00022	.00000	.00038	.00003	.00039	.00041	.00004	.00000	.00000	.00000	.00000	.00006	.00002
A	2	.00000	.00000	.00000	.00000	.00006	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00027	.00009
A	3	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
A	4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
A	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
A	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
B	1	.00269	.00383	.00497	.00357	.00171	.00114	.00067	.00098	.00233	.00387	.00277	.00275	.00076	.00018	.00049	.00056
B	2	.00179	.00231	.00308	.00194	.00142	.00078	.00047	.00030	.00153	.00410	.00471	.00135	.00023	.00044	.00109	.00063
B	3	.00009	.00100	.00152	.00075	.00017	.00023	.00002	.00014	.00060	.00249	.00252	.00083	.00007	.00040	.00016	.00003
B	4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
B	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
B	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
C	1	.00231	.00445	.00643	.00528	.00487	.00285	.00152	.00302	.00330	.00407	.00408	.00239	.00117	.00094	.00061	.00094
C	2	.00154	.00503	.00578	.00275	.00137	.00145	.00100	.00070	.00224	.00554	.00376	.00132	.00053	.00056	.00038	.00023
C	3	.00161	.00602	.00724	.00257	.00247	.00069	.00047	.00053	.00232	.00615	.00413	.00369	.00254	.00176	.00132	.00030
C	4	.00009	.00063	.00010	.00002	.00004	.00000	.00000	.00000	.00018	.00097	.00095	.00100	.00023	.00024	.00015	.00000
C	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00012	.00058	.00000	.00000	.00000	.00000	.00000
C	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DD	1	.00488	.00772	.00940	.00580	.00608	.00342	.00194	.00367	.00622	.00598	.00461	.00249	.00122	.00066	.00137	.00245
DD	2	.00624	.01381	.01818	.01157	.00756	.00231	.00116	.00324	.01225	.01586	.00929	.00767	.00217	.00201	.00372	.00201
DD	3	.01066	.01907	.00791	.00418	.00351	.00152	.00011	.00150	.01596	.03510	.01843	.00981	.00603	.00583	.00530	.00276
DD	4	.00948	.02207	.00644	.00104	.00044	.00047	.00001	.00037	.00528	.02184	.02676	.01494	.00441	.00188	.00129	.00183
DD	5	.00110	.00334	.00381	.00000	.00000	.00000	.00000	.00000	.00009	.00275	.00716	.00535	.00105	.00027	.00001	.00000
DD	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00024	.00287	.00080	.00000	.00000	.00000	.00000
DN	1	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	2	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	3	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
DN	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
EF	1	.00949	.02412	.04174	.02101	.01249	.00811	.00479	.00728	.01674	.01439	.00708	.00215	.00102	.00104	.00120	.00243
EF	2	.00740	.01782	.02626	.00996	.00351	.00141	.00070	.00294	.01266	.01464	.00739	.00340	.00222	.00202	.00294	.00167
EF	3	.00174	.00481	.00397	.00101	.00006	.00000	.00000	.00005	.00155	.00402	.00159	.00029	.00035	.00008	.00079	.00013
EF	4	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
EF	5	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
EF	6	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000

PREDICTED CONCENTRATION FREQUENCY DISTRIBUTION

TEXAS EPISODIC MODEL CONCENTRATION PREDICTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

PREDICTED CONCENTRATIONS FOR WIND SECTORS 1-16 (MICROGRAMS/CUBIC METER):RECEPTOR 1, AT X=3473.29, Y=5551.53

STABILITY CLASS	WIND SPEED CLASS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1	174.5	179.7	187.3	194.7	214.7	249.0	177.8	193.3	190.4	180.1	193.7	208.4	191.9	178.4	174.1	174.2
A	2	106.5	109.6	114.0	118.6	132.0	154.5	108.9	120.3	119.3	110.2	119.5	131.5	119.1	108.8	106.2	106.2
A	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	1	182.0	184.1	190.6	199.6	248.0	324.8	143.7	186.9	175.1	183.2	183.9	289.4	209.5	177.8	175.6	175.2
B	2	111.9	112.6	115.4	121.6	162.4	257.9	82.0	126.5	117.2	118.6	113.4	196.5	132.2	108.3	107.2	106.9
B	3	62.0	62.1	63.2	66.9	94.2	172.8	43.2	79.0	73.4	69.9	63.0	116.9	74.8	59.6	59.1	58.8
B	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
C	1	188.6	189.9	207.6	221.5	257.4	244.1	159.5	185.7	171.9	181.2	167.7	290.7	216.2	181.0	178.4	177.2
C	2	118.0	116.1	125.0	135.4	165.0	195.2	86.8	115.0	103.3	112.6	97.1	215.7	136.8	110.1	109.0	108.0
C	3	65.1	64.0	68.0	74.6	95.1	154.2	40.9	69.1	58.7	66.8	51.4	143.5	77.4	60.5	60.1	59.4
C	4	42.9	41.3	43.6	48.1	62.8	121.0	24.0	47.9	39.7	45.7	32.6	100.7	50.5	39.0	38.6	38.3
C	5	31.1	29.8	31.4	34.7	45.8	96.6	16.4	36.4	29.7	34.4	23.3	75.6	36.6	28.1	28.0	27.6
C	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DD	1	192.3	209.2	255.9	278.7	317.5	223.7	180.2	209.2	165.7	146.6	207.7	243.2	225.2	198.4	187.2	189.4
DD	2	120.7	128.4	156.5	171.8	207.4	139.9	108.2	127.5	113.0	114.6	115.9	162.1	139.6	120.2	115.1	115.5
DD	3	69.7	71.0	85.5	95.5	122.0	81.7	58.1	70.1	61.9	63.4	53.5	112.1	78.4	65.8	63.7	63.4
DD	4	47.1	45.9	54.8	61.9	81.5	57.5	36.5	45.2	39.8	41.1	30.2	84.5	51.2	42.3	41.2	40.8
DD	5	34.7	33.1	39.4	44.7	59.9	44.4	25.8	32.6	28.7	29.8	19.8	66.9	37.1	30.5	29.8	29.4
DD	6	27.1	25.4	30.2	34.4	46.5	36.0	19.5	25.2	22.0	23.2	14.2	54.4	28.6	23.4	22.9	22.6
DN	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	1	120.1	148.2	221.3	259.2	296.5	174.2	92.9	151.0	109.7	100.5	151.7	176.5	173.6	127.6	89.6	114.4
EF	2	74.8	90.8	135.0	158.6	185.1	105.4	56.5	92.2	67.4	61.4	89.3	109.5	106.4	77.7	55.3	69.9
EF	3	42.3	50.2	75.4	87.6	104.4	57.6	30.9	50.8	37.2	33.9	47.0	62.0	58.9	42.6	30.8	38.6
EF	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N

STANDARD STATISTICAL PARAMETERS FOR DISTRIBUTION: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 1, AT X=3473.29 KM, Y=5551.53 KM. CONCENTRATIONS IN MICROGRAMS PER CUBIC METER

ARITHMETIC MEAN CONCENTRATION = 122.62 ARITHMETIC STANDARD DEVIATION = 69.44

GEOMETRIC MEAN CONCENTRATION = 103.15 GEOMETRIC STANDARD DEVIATION = 1.87

PREDICTED 2ND HIGHEST CONCENTRATION FOR YEAR = 533.37. RELATIVE FREQUENCY OF OCCURRENCE OF ZERO CONCENTRATION = .0000

PARAMETERS DERIVED FROM ARITHMETIC MEAN AND STANDARD DEVIATION ASSUMING LOGNORMALITY (AFTER LARSEN):

GEOMETRIC MEAN CONCENTRATION = 105.92
GEOMETRIC STANDARD DEVIATION = 1.69
2ND-HIGH 24-HR CONCENTRATION = 427.13

LOGNORMAL DISTRIBUTION DERIVED FROM NORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10

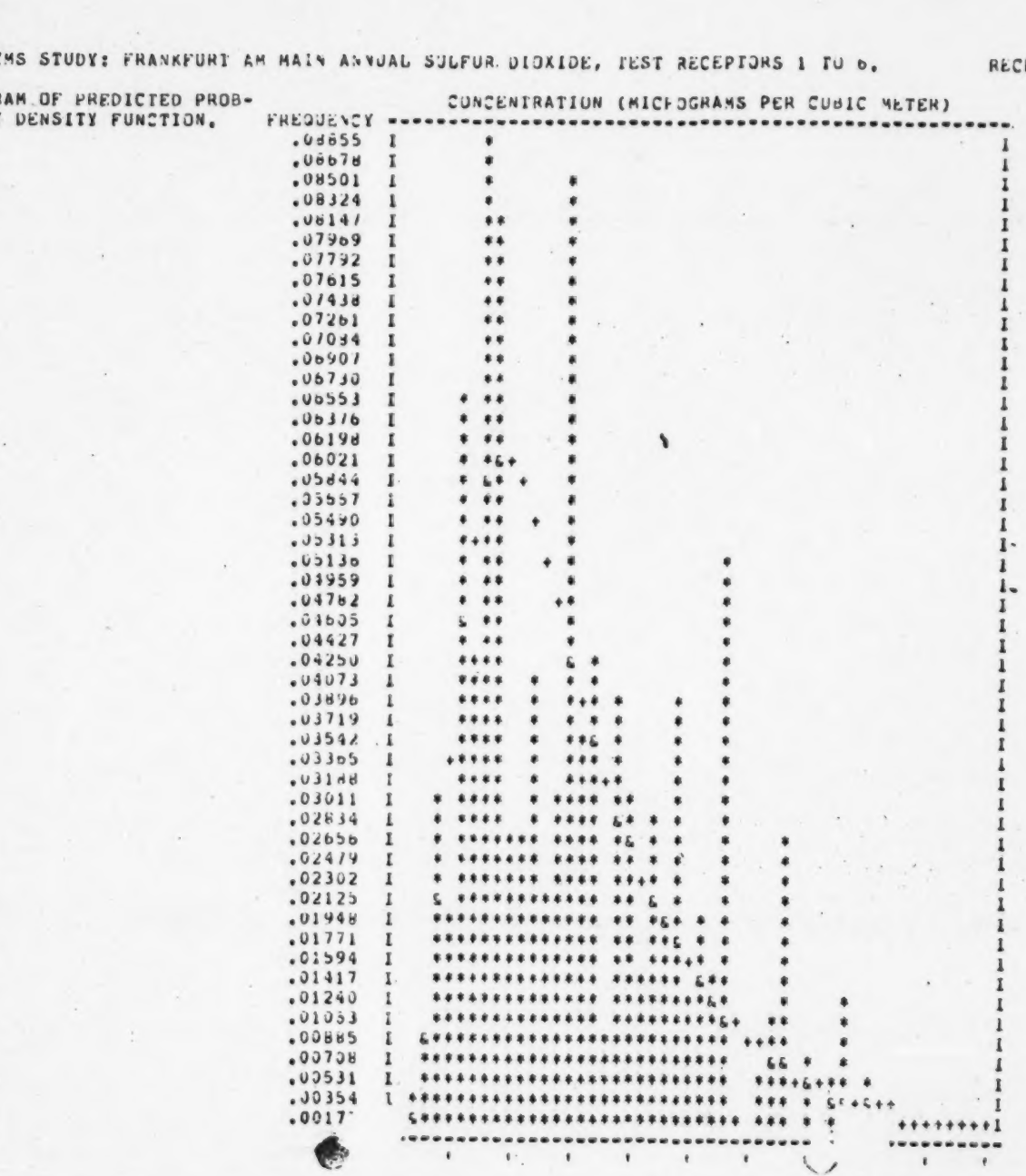
LOGNORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 1 AT X=3473.29 KM, Y=5551.53 KM.
& = COINCIDENCE OF (*) AND (+).
* = PREDICTED PROBABILITY DENSITY FN.
+ = LOGNORMAL FIT TO PREDICTIONS.

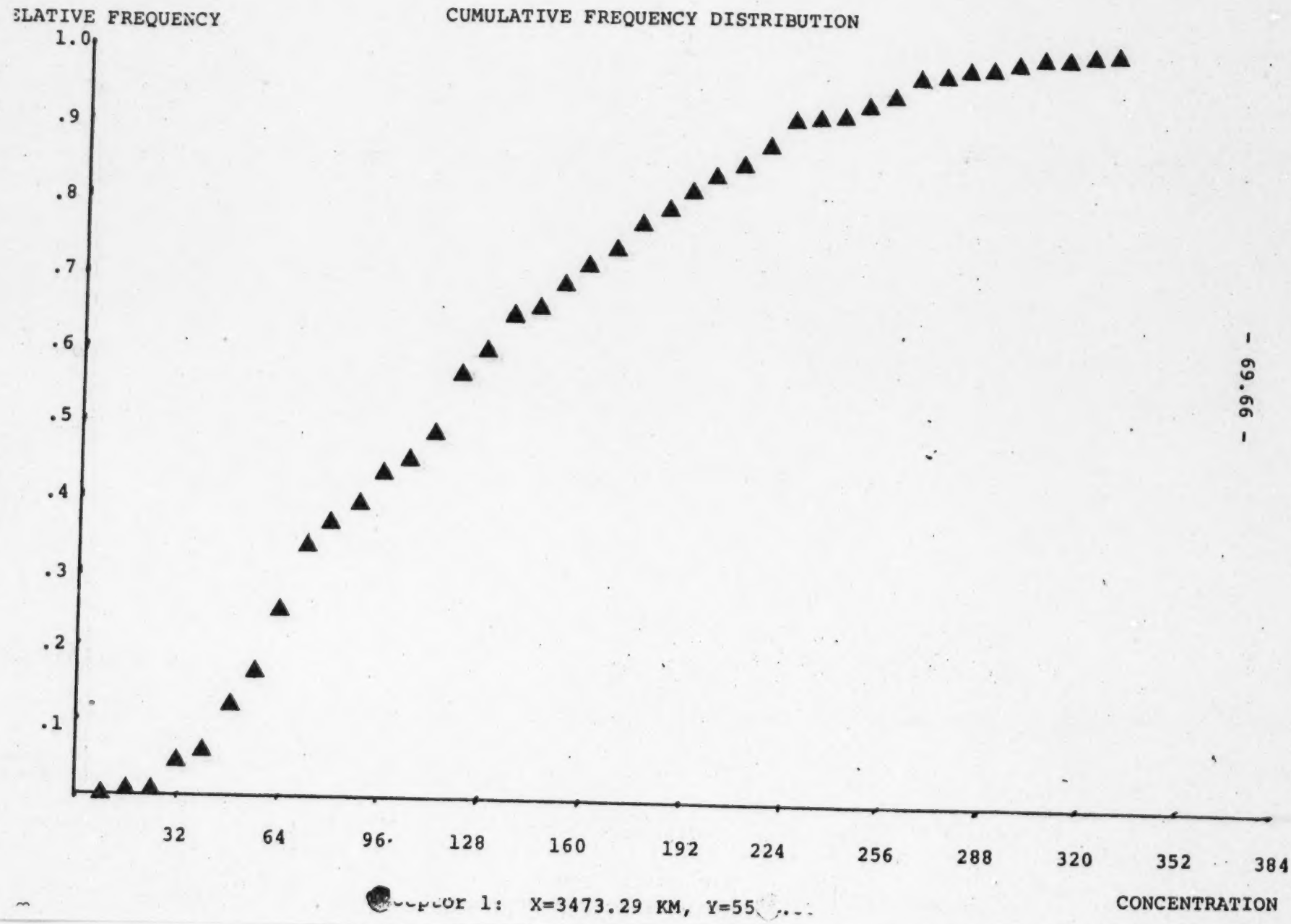
HISTOGRAM OF PREDICTED PROBABILITY DENSITY FUNCTION.



PREDICTED CUMULATIVE FREQUENCY DISTRIBUTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 1 AT X=3473.29 KM, Y=5551.53 KM.

CONCENTRATION LEVEL (MICROGRAMS PER CUBIC METER)	PREDICTED FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL	FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL FOR A LOGNORMAL DELTA DISTRIBUTION FIT TO THE DATA
8.00	.00030	.00002
16.00	.00287	.00143
24.00	.01085	.00960
32.00	.04152	.03050
40.00	.06045	.06472
48.00	.12550	.11038
56.00	.16776	.16410
64.00	.25631	.22243
72.00	.33734	.28249
80.00	.36308	.34207
88.00	.39037	.39965
96.00	.43133	.45424
104.00	.45272	.50525
112.00	.48319	.55242
120.00	.56793	.59569
128.00	.60308	.63515
136.00	.64619	.67096
144.00	.65556	.70335
152.00	.69404	.73257
160.00	.72439	.75888
168.00	.73893	.78254
176.00	.76662	.80380
184.00	.78685	.82289
192.00	.82635	.84002
200.00	.83907	.85540
208.00	.85767	.86921
216.00	.87174	.88161
224.00	.92335	.89275
232.00	.92457	.90277
240.00	.92457	.91177
248.00	.92991	.91987
256.00	.94140	.92717
264.00	.96836	.93375
272.00	.96806	.93968
280.00	.97486	.94503
288.00	.97486	.94987
296.00	.98030	.95424
304.00	.99249	.95820
312.00	.99249	.96178
320.00	.99857	.96502
328.00	.99971	.96797
336.00	.99971	.97064
344.00	.99971	.97307
352.00	.99971	.97528
360.00	.99971	.97729
368.00	.99971	.97912
376.00	.99971	.98079
384.00	.99971	.98231
392.00	.99971	.98370
400.00	.99971	.98497



Receptor 1: X=3473.29 KM, Y=55...

PREDICTED CONCENTRATION FREQUENCY DISTRIBUTION

TEXAS EPISODIC MODEL CONCENTRATION PREDICTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

PREDICTED CONCENTRATIONS FOR WIND SECTORS 1-16 (MICROGRAMS/CUBIC METER):RECEPTOR 2, AT X=3479.25, Y=5553.15

STABILITY CLASS	WIND SPEED CLASS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1	152.4	149.8	135.3	124.4	127.6	129.5	128.5	123.2	123.3	129.4	142.6	155.1	147.9	151.4	165.6	162.6
A	2	92.9	91.4	82.6	75.9	78.3	79.2	78.5	75.2	75.2	79.1	87.7	96.7	90.6	92.4	101.3	99.5
A	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	1	152.8	150.7	136.7	129.6	142.3	134.8	132.9	123.9	125.7	155.2	155.2	223.8	166.6	153.8	176.8	167.0
B	2	93.2	92.0	83.7	79.4	88.9	82.9	82.4	75.8	76.9	97.7	96.6	145.8	104.3	94.3	109.6	102.6
B	3	51.3	50.6	46.2	43.9	49.9	45.9	45.9	41.8	42.4	54.9	54.0	84.2	58.5	52.1	61.0	58.6
B	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
C	1	171.0	167.7	143.7	133.0	157.1	138.3	133.1	121.2	124.1	160.2	164.1	309.0	185.9	171.1	215.2	193.3
C	2	104.3	102.3	88.0	81.9	99.9	85.0	84.4	74.3	76.1	106.5	103.8	223.0	120.1	104.7	137.2	119.5
C	3	57.4	56.3	48.6	45.4	56.8	47.0	48.2	41.0	42.1	62.6	58.8	137.0	69.0	57.8	77.6	66.4
C	4	37.0	36.4	31.4	29.4	37.1	30.4	31.6	26.5	27.2	41.5	38.4	92.1	45.3	37.3	50.8	43.0
C	5	26.7	26.2	22.7	21.2	27.0	21.9	23.0	19.1	19.6	30.4	27.8	67.8	32.9	26.9	36.6	31.1
C	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DD	1	217.0	209.8	157.9	123.3	168.4	141.6	122.1	108.0	111.8	131.9	173.8	261.1	207.2	224.3	252.9	254.5
DD	2	132.3	128.1	96.7	77.6	114.8	87.7	76.2	66.5	68.9	67.0	110.3	200.9	132.7	137.8	168.4	157.3
DD	3	72.9	70.6	53.4	43.9	69.3	48.9	44.5	37.0	38.2	52.2	63.2	152.7	78.1	76.3	100.3	87.8
DD	4	47.0	45.5	34.5	28.6	46.7	31.8	30.1	24.0	24.8	35.5	41.6	119.3	52.5	49.3	69.1	57.1
DD	5	33.9	32.8	24.9	20.8	34.4	23.0	22.4	17.4	17.9	26.4	30.4	94.6	38.7	35.6	51.5	41.3
DD	6	26.0	25.2	19.1	16.0	26.8	17.7	17.5	13.3	13.7	20.6	23.6	77.3	30.1	27.3	40.5	31.8
DN	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	1	219.8	202.1	125.8	64.5	126.7	102.1	64.9	44.1	51.0	72.2	146.6	257.3	206.0	247.4	296.2	283.5
EF	2	134.0	123.5	77.2	40.5	83.6	63.0	39.8	27.0	31.2	45.2	90.6	170.0	127.1	151.8	183.4	173.2
EF	3	73.8	68.1	42.8	22.9	49.7	35.1	22.1	14.9	17.3	25.6	50.6	106.4	70.7	84.0	102.9	95.6
EF	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N

STANDARD STATISTICAL PARAMETERS FOR DISTRIBUTION: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 2, AT X=3479.25 KM, Y=5553.15 KM. CONCENTRATIONS IN MICROGRAMS PER CUBIC METER

ARITHMETIC MEAN CONCENTRATION = 96.69 ARITHMETIC STANDARD DEVIATION = 53.98

GEOMETRIC MEAN CONCENTRATION = 82.73 GEOMETRIC STANDARD DEVIATION = 1.78

PREDICTED 2ND HIGHEST CONCENTRATION FOR YEAR = 376.65. RELATIVE FREQUENCY OF OCCURRENCE OF ZERO CONCENTRATION = .0000

PARAMETERS DERIVED FROM ARITHMETIC MEAN AND STANDARD DEVIATION ASSUMING LOGNORMALITY (AFTER LARSEN):

GEOMETRIC MEAN CONCENTRATION = 84.42
GEOMETRIC STANDARD DEVIATION = 1.68
2ND-HIGH 24-HR CONCENTRATION = 332.19

LOGNORMAL DISTRIBUTION DERIVED FROM NORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

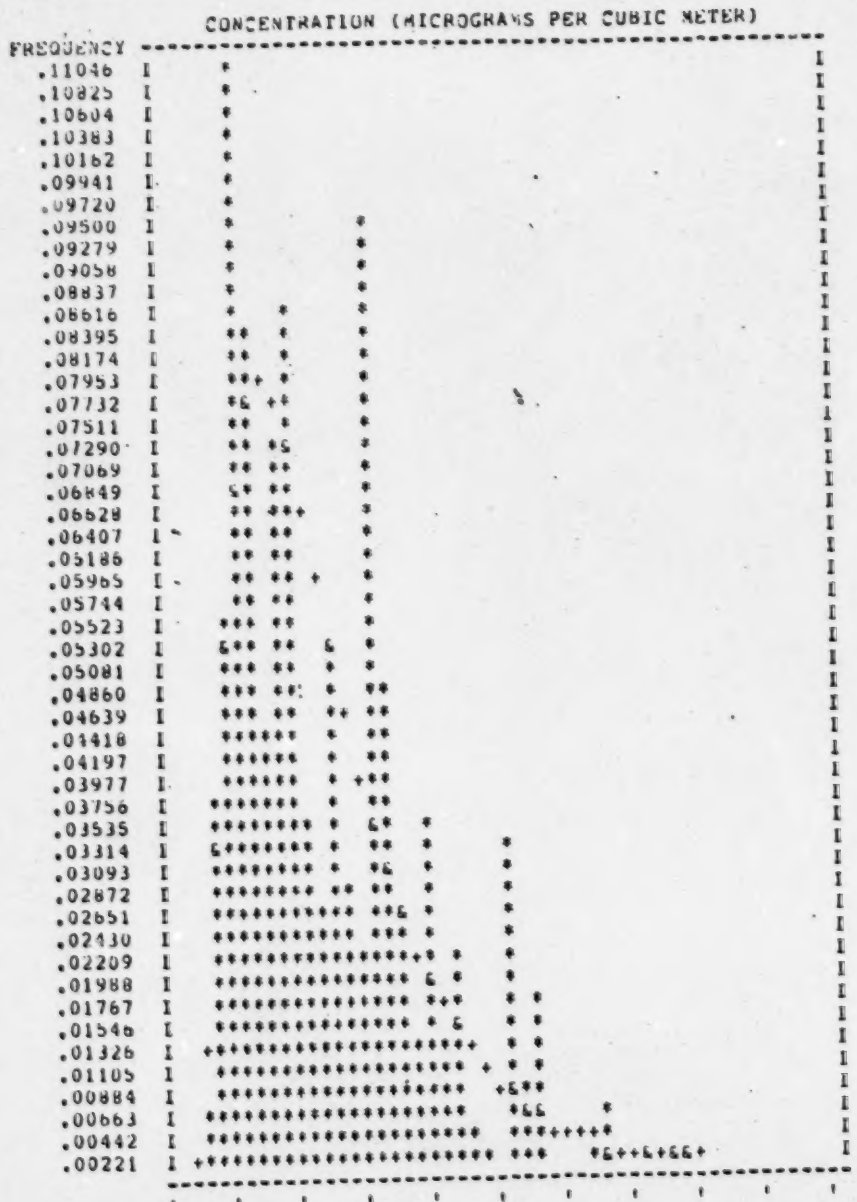
LOGNORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 2 AT X=3479.25 KM, Y=5553.15 KM.
& = COINCIDENCE OF (*) AND (+).
* = PREDICTED PROBABILITY DENSITY FN.
+ = LOGNORMAL FIT TO PREDICTIONS.

HISTOGRAM OF PREDICTED PROBABILITY DENSITY FUNCTION.



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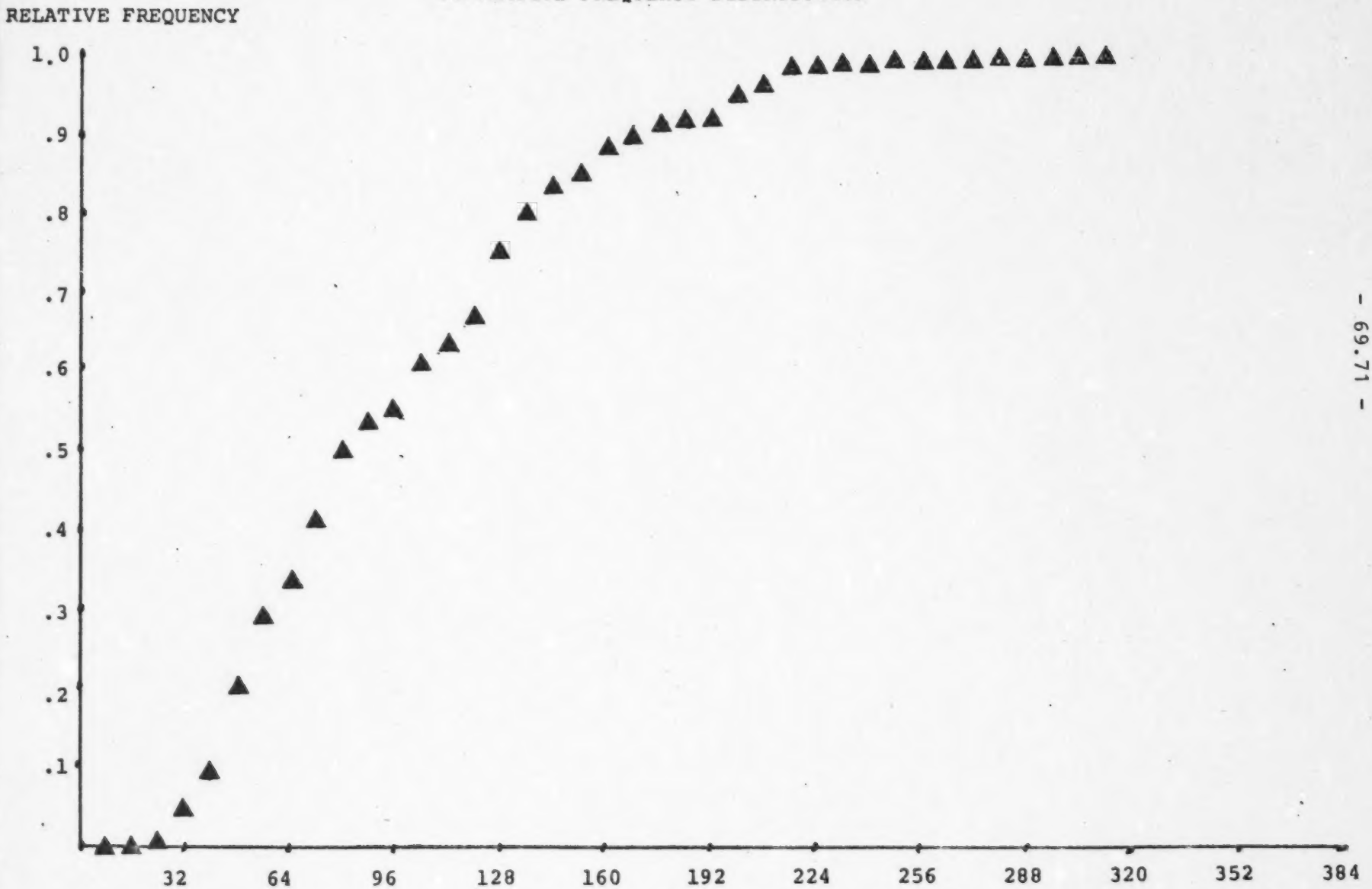
PREDICTED CUMULATIVE FREQUENCY DISTRIBUTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 2 AT X=3479.25 KM, Y=5553.15 KM.

CONCENTRATION LEVEL (MICROGRAMS PER CUBIC METER)	PREDICTED FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL	FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL FOR A LOGNORMAL DELTA DISTRIBUTION FIT TO THE DATA
8.00	.00000	.00003
16.00	.00005	.00218
24.00	.00618	.01588
32.00	.04432	.04966
40.00	.09857	.10365
48.00	.20903	.17242
56.00	.29308	.24915
64.00	.33714	.32799
72.00	.41036	.40474
80.00	.49629	.47676
88.00	.53119	.54265
96.00	.55780	.60183
104.00	.61014	.65431
112.00	.63857	.70040
120.00	.66130	.74063
128.00	.75609	.77555
136.00	.80432	.80578
144.00	.83038	.83188
152.00	.84466	.85439
160.00	.88026	.87378
168.00	.89426	.89049
176.00	.91699	.90487
184.00	.92042	.91727
192.00	.92159	.92797
200.00	.92253	.93720
208.00	.95656	.94517
216.00	.96489	.95206
224.00	.98333	.95803
232.00	.98419	.96321
240.00	.98419	.96770
248.00	.98523	.97160
256.00	.98768	.97500
264.00	.99369	.97796
272.00	.99369	.98055
280.00	.99369	.98281
288.00	.99612	.98478
296.00	.99612	.98651
304.00	.99732	.98803
312.00	.99971	.98937
320.00	.99971	.99054
328.00	.99971	.99158
336.00	.99971	.99249
344.00	.99971	.99329
352.00	.99971	.99401
360.00	.99971	.99464
368.00	.99971	.99520
376.00	.99971	.99569
384.00	.99971	.99613
392.00	.99971	.99653

CUMULATIVE FREQUENCY DISTRIBUTION



Receptor 2: X=3479.25 KM, Y=5553.15 KM

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N

TEXAS EPISODIC MODEL CONCENTRATION PREDICTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

PREDICTED CONCENTRATIONS FOR WIND SECTORS 1-16 (MICROGRAMS/CUBIC METER)(RECEPTOR 3, AT X=3475.76, Y=5553.98

STABILITY CLASS	WIND SPEED CLASS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1	118.5	117.9	128.2	147.6	152.8	139.9	122.7	131.2	129.1	143.8	129.7	133.5	135.5	135.7	116.4	112.8
A	2	72.3	71.9	78.2	90.0	93.5	85.5	74.9	79.9	78.8	88.2	79.6	82.2	82.9	83.1	71.0	68.9
A	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	1	118.3	119.5	130.2	149.4	157.4	153.1	136.7	131.0	142.5	252.9	131.3	166.4	135.9	147.3	115.7	137.2
B	2	72.1	73.1	79.6	91.2	96.8	94.4	84.0	79.5	90.6	176.9	81.1	106.4	83.5	92.0	70.5	87.1
B	3	39.7	40.3	43.8	50.2	53.7	52.3	46.5	43.6	51.3	106.3	45.1	60.7	46.2	51.4	38.8	49.2
B	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
C	1	123.5	122.5	140.5	176.9	197.0	184.8	155.0	141.1	132.6	229.8	141.8	221.5	143.8	167.4	118.8	148.2
C	2	75.0	75.4	85.9	108.0	121.5	115.6	96.0	84.9	82.0	186.8	85.3	146.6	88.0	108.0	72.3	106.7
C	3	41.1	41.8	47.4	59.5	67.5	64.7	53.3	46.2	45.8	128.8	46.3	85.2	48.5	61.6	39.7	66.5
C	4	26.5	27.0	30.6	38.4	43.7	42.0	34.5	29.6	29.7	91.6	29.7	56.3	31.3	40.3	25.6	44.9
C	5	19.1	19.5	22.0	27.7	31.6	30.4	25.0	21.3	21.5	69.2	21.4	41.0	22.6	29.3	18.5	33.2
C	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DD	1	139.8	130.4	162.6	253.8	305.6	225.9	153.9	180.6	151.6	161.9	163.0	185.2	176.2	188.4	119.1	109.7
DD	2	85.2	79.4	99.3	155.2	193.9	148.6	98.8	107.4	93.2	109.0	100.2	145.4	107.5	125.8	73.0	74.0
DD	3	46.6	43.9	54.8	85.6	110.0	87.2	55.9	57.7	51.5	72.1	54.3	105.4	59.2	75.0	40.4	49.9
DD	4	29.9	28.4	35.3	55.3	71.9	57.9	36.2	36.8	33.3	54.5	34.1	78.4	38.2	50.1	26.1	42.2
DD	5	21.5	20.5	25.5	39.9	52.2	42.4	26.1	26.3	24.1	42.5	24.1	60.6	27.5	36.8	18.8	34.1
DD	6	16.4	15.8	19.6	30.6	40.2	32.8	20.2	20.1	18.5	34.5	18.2	48.4	21.1	28.5	14.5	29.2
DN	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	1	142.9	126.2	160.1	324.8	412.0	248.9	124.4	194.4	135.3	143.9	161.0	139.3	178.2	167.2	71.6	69.9
EF	2	87.2	76.8	97.6	198.8	256.5	154.1	76.9	118.0	83.3	88.8	98.3	96.0	109.0	103.8	44.0	45.0
EF	3	48.0	42.2	53.7	109.8	144.0	86.2	42.8	64.7	46.2	49.8	54.0	59.1	60.1	58.5	24.5	26.5
EF	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N

STANDARD STATISTICAL PARAMETERS FOR DISTRIBUTION: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 3, AT X=3475.76 KM, Y=5553.98 KM. CONCENTRATIONS IN MICROGRAMS PER CUBIC METER

ARITHMETIC MEAN CONCENTRATION = 111.00 ARITHMETIC STANDARD DEVIATION = 71.74

GEOMETRIC MEAN CONCENTRATION = 91.73 GEOMETRIC STANDARD DEVIATION = 1.89

PREDICTED 2ND HIGHEST CONCENTRATION FOR YEAR = 487.00. RELATIVE FREQUENCY OF OCCURRENCE OF ZERO CONCENTRATION = .0000

PARAMETERS DERIVED FROM ARITHMETIC MEAN AND STANDARD DEVIATION ASSUMING LOGNORMALITY (AFTER LARSEN):

GEOMETRIC MEAN CONCENTRATION = 93.23
GEOMETRIC STANDARD DEVIATION = 1.81
2ND-HIGH 24-HR CONCENTRATION = 440.90

LOGNORMAL DISTRIBUTION DERIVED FROM NORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

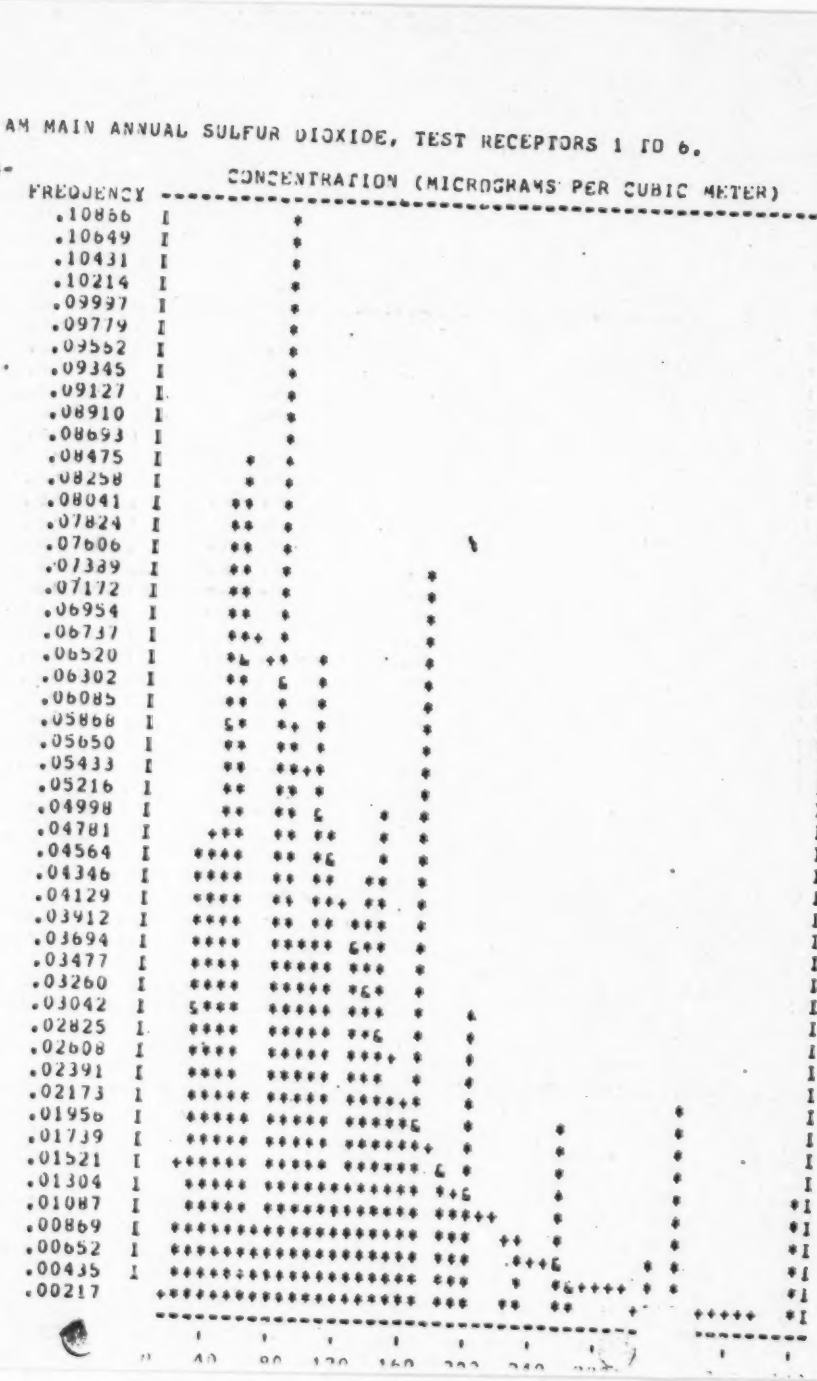
LOGNORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

HISTOGRAM OF PREDICTED PROBABILITY DENSITY FUNCTION.

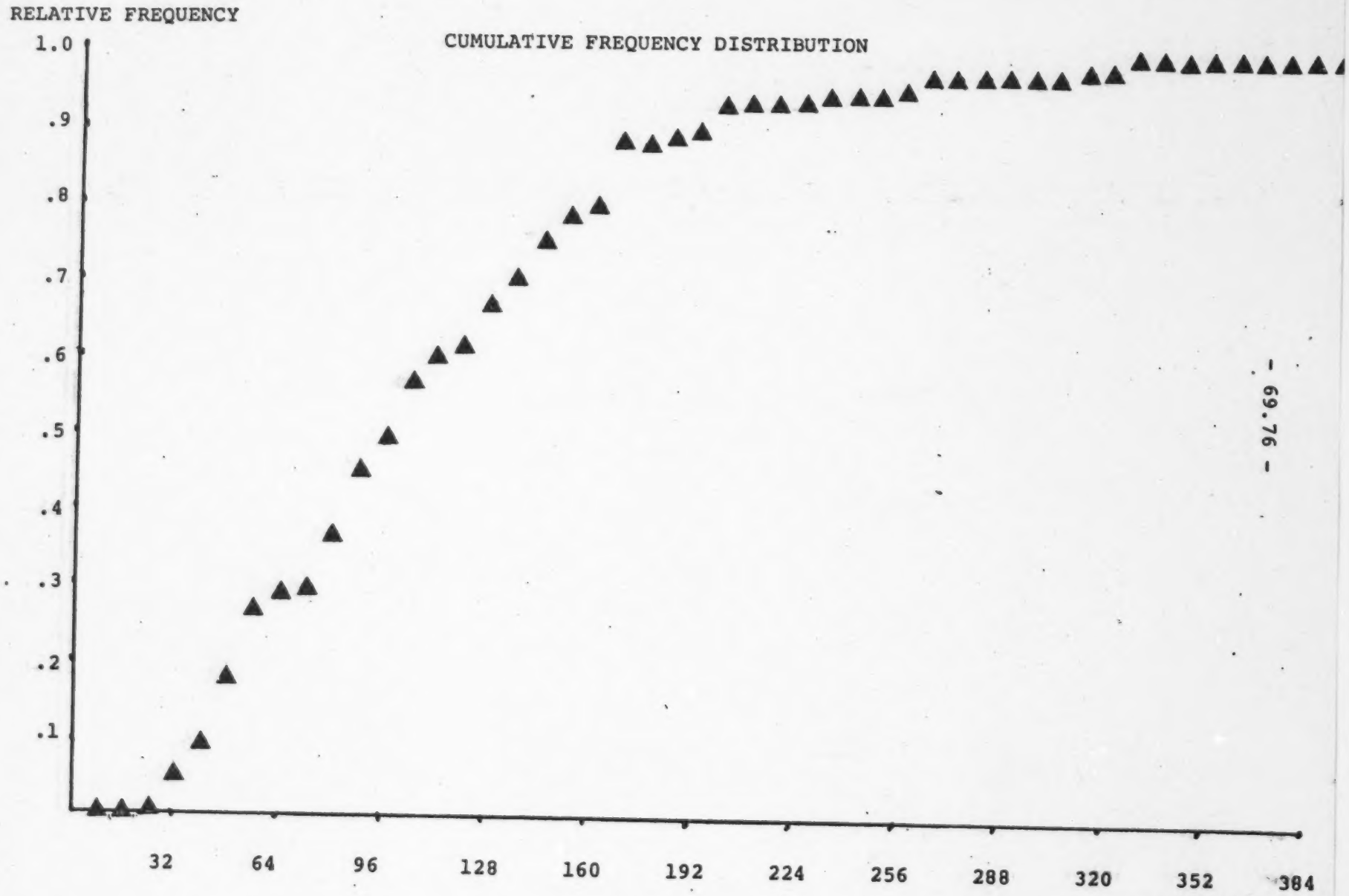
RECEPTOR 3 AT X=3475.76 KM, Y=5553.98 KM.
& = COINCIDENCE OF (*) AND (+).
* = PREDICTED PROBABILITY DENSITY FN.
+ = LOGNORMAL FIT TO PREDICTIONS.



PREDICTED CUMULATIVE FREQUENCY DISTRIBUTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 3 AT X=3475.76 KM, Y=5553.98 KM.

CONCENTRATION LEVEL (MICROGRAMS PER CUBIC METER)	PREDICTED FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL	FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL FOR A LOGNORMAL DELTA DISTRIBUTION FIT TO THE DATA
8.00	.00000	.00006
16.00	.00000	.00297
24.00	.00790	.01733
32.00	.05310	.04855
40.00	.09847	.09552
48.00	.17819	.15379
56.00	.26368	.21844
64.00	.28443	.28533
72.00	.29364	.35140
80.00	.40230	.41467
88.00	.45804	.47393
96.00	.49505	.52857
104.00	.56077	.57839
112.00	.60842	.62344
120.00	.62188	.66393
128.00	.66156	.70017
136.00	.70575	.73250
144.00	.75534	.76129
152.00	.77783	.78688
160.00	.79772	.80960
168.00	.87126	.82978
176.00	.87126	.84769
184.00	.88655	.86360
192.00	.89829	.87772
200.00	.92796	.89027
208.00	.92796	.90143
216.00	.92796	.91137
224.00	.93035	.92021
232.00	.93784	.92810
240.00	.93784	.93514
248.00	.93784	.94143
256.00	.95662	.94705
264.00	.96013	.95208
272.00	.96013	.95659
280.00	.96013	.96063
288.00	.96013	.96426
296.00	.96013	.96752
304.00	.96013	.97046
312.00	.96621	.97311
320.00	.96621	.97549
328.00	.98722	.97764
336.00	.98722	.97959
344.00	.98722	.98134
352.00	.98722	.98294
360.00	.98722	.98438
368.00	.98722	.98569
376.00	.98722	.98687
384.00	.98722	.98795
392.00	.98722	.98894
400.00	.99971	.98983



Rec or 3: X=3475.76 KM, Y=5553.9

PREDICTED CONCENTRATION FREQUENCY DISTRIBUTION

TEXAS EPISODIC MODEL CONCENTRATION PREDICTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

PREDICTED CONCENTRATIONS FOR WIND SECTORS 1-16 (MICROGRAMS/CUBIC METER):RECEPTOR 4, AT X=3467.00, Y=5552.00

STABILITY CLASS	WIND SPEED CLASS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1	93.6	96.1	98.8	96.6	102.3	101.9	122.5	138.7	130.7	244.4	112.5	90.7	86.8	86.7	90.6	95.4
A	2	57.1	58.6	60.4	58.9	63.0	62.3	78.3	89.8	83.7	160.7	70.1	55.3	53.0	52.9	55.2	58.2
A	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	1	96.0	96.4	107.0	96.9	120.0	140.4	94.2	100.0	90.6	162.8	111.1	90.5	86.8	86.8	92.6	98.7
B	2	58.7	58.9	66.9	59.2	75.9	89.1	65.8	82.0	62.4	193.8	71.1	55.2	53.0	52.9	56.7	60.4
B	3	32.3	32.5	37.5	32.6	43.0	50.4	43.4	62.6	43.5	207.5	40.8	30.4	29.1	29.1	31.3	33.3
B	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
C	1	106.1	105.7	127.9	105.9	170.9	177.9	92.1	87.8	88.7	140.6	111.6	95.7	88.7	88.1	98.6	111.4
C	2	64.9	64.6	82.2	64.7	110.9	122.5	56.5	55.9	54.2	110.8	70.2	58.4	54.1	53.7	60.5	66.1
C	3	35.8	35.6	47.1	35.6	63.7	72.9	31.9	37.0	30.1	113.7	39.7	32.2	29.8	29.6	33.4	37.8
C	4	23.2	23.0	31.0	23.0	41.9	48.5	21.3	28.5	19.7	122.6	25.9	20.8	19.2	19.1	21.6	24.4
C	5	16.7	16.6	22.5	16.6	30.5	35.5	15.7	23.0	14.4	117.7	18.8	15.0	13.8	13.8	15.6	17.6
C	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DD	1	135.2	146.3	155.5	141.6	235.7	164.4	108.4	101.0	100.6	116.5	142.4	122.3	103.7	101.8	116.1	146.7
DD	2	83.6	89.9	103.6	86.7	174.3	113.5	66.1	61.8	61.4	78.6	91.1	74.9	63.3	62.1	71.6	94.1
DD	3	46.5	49.8	64.4	47.9	113.6	76.7	36.4	34.1	33.8	49.1	52.1	41.3	34.8	34.2	40.0	53.1
DD	4	30.2	32.2	45.0	30.9	79.3	55.7	23.5	22.0	21.8	35.4	34.1	26.7	22.5	22.0	25.9	34.6
DD	5	21.8	23.2	33.8	22.3	59.5	42.8	16.9	15.9	15.7	29.0	24.8	19.3	16.2	15.9	18.6	25.1
DD	6	16.8	17.9	26.6	17.1	46.7	34.3	13.0	12.3	12.1	24.5	19.1	14.8	12.4	12.2	14.4	19.3
DN	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	1	128.2	157.4	164.6	144.8	260.2	168.0	82.7	71.9	75.4	82.9	133.1	117.9	81.5	75.5	86.9	149.0
EF	2	78.4	96.9	104.4	88.7	169.8	105.1	50.4	44.0	46.0	51.8	82.9	72.3	49.7	46.1	54.3	92.0
EF	3	43.3	53.8	60.2	49.0	101.1	59.8	27.8	24.3	25.3	29.2	46.5	40.0	27.4	25.4	30.0	52.1
EF	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N

STANDARD STATISTICAL PARAMETERS FOR DISTRIBUTION: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 4, AT X=3467.00 KM, Y=5552.00 KM.

CONCENTRATIONS IN MICROGRAMS PER CUBIC METER

ARITHMETIC MEAN CONCENTRATION = 85.13 ARITHMETIC STANDARD DEVIATION = 50.11

GEOMETRIC MEAN CONCENTRATION = 71.36 GEOMETRIC STANDARD DEVIATION = 1.85

PREDICTED 2ND HIGHEST CONCENTRATION FOR YEAR = 359.82. RELATIVE FREQUENCY OF OCCURRENCE OF ZERO CONCENTRATION = .0000

PARAMETERS DERIVED FROM ARITHMETIC MEAN AND STANDARD DEVIATION ASSUMING LOGNORMALITY (AFTER LARSEN):

GEOMETRIC MEAN CONCENTRATION = 73.36
GEOMETRIC STANDARD DEVIATION = 1.73
2ND-HIGH 24-HR CONCENTRATION = 307.94

LOGNORMAL DISTRIBUTION DERIVED FROM NORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

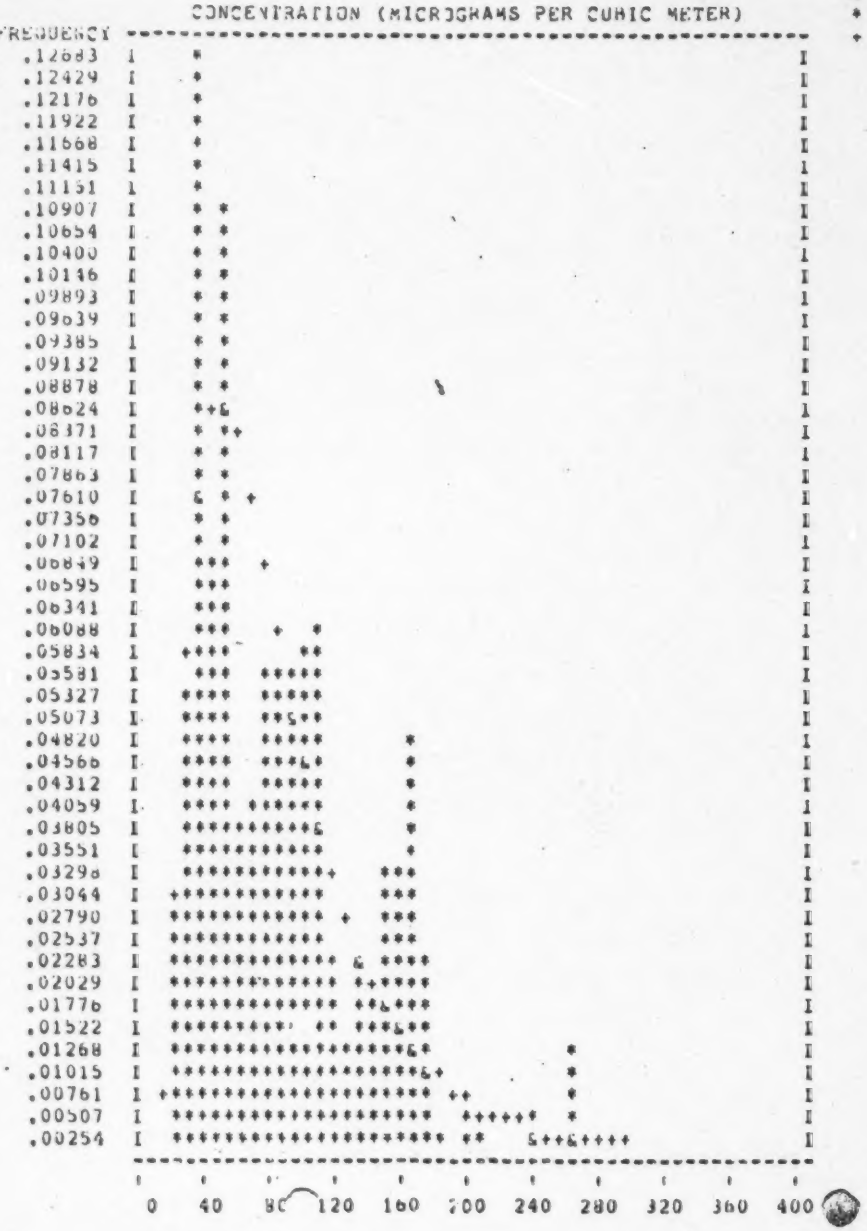
LOGNORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 4 AT X=3467.00 KM, Y=5552.00 KM.
& = COINCIDENCE OF (*) AND (+).
* = PREDICTED PROBABILITY DENSITY FN.
+ = LOGNORMAL FIT TO PREDICTIONS.

HISTOGRAM OF PREDICTED PROBABILITY DENSITY FUNCTION.



PREDICTED CUMULATIVE FREQUENCY DISTRIBUTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 4 AT X=3467.00 KM, Y=5552.00 KM.

CONCENTRATION LEVEL (MICROGRAMS PER CUBIC METER)	PREDICTED FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL	FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL FOR A LOGNORMAL DELTA DISTRIBUTION FIT TO THE DATA
8.00	.00000	.00019
16.00	.00116	.00754
24.00	.02995	.03826
32.00	.08331	.09618
40.00	.21014	.17338
48.00	.27836	.25962
56.00	.38751	.34682
64.00	.42650	.42981
72.00	.46814	.50582
80.00	.52432	.57372
88.00	.58076	.63337
96.00	.63781	.68518
104.00	.69659	.72985
112.00	.75791	.76817
120.00	.77950	.80094
128.00	.79258	.82891
136.00	.81444	.85278
144.00	.83145	.87314
152.00	.86506	.89051
160.00	.89858	.90534
168.00	.94761	.91803
176.00	.97166	.92889
184.00	.97451	.93820
192.00	.97451	.94619
200.00	.97861	.95307
208.00	.98110	.95899
216.00	.98110	.96411
224.00	.98110	.96853
232.00	.98110	.97236
240.00	.98718	.97568
248.00	.98722	.97857
256.00	.98722	.98108
264.00	.99971	.98328
272.00	.99971	.98519
280.00	.99971	.98687
288.00	.99971	.98834
296.00	.99971	.98963
304.00	.99971	.99076
312.00	.99971	.99176
320.00	.99971	.99264
328.00	.99971	.99342
336.00	.99971	.99411
344.00	.99971	.99472
352.00	.99971	.99526
360.00	.99971	.99574
368.00	.99971	.99617
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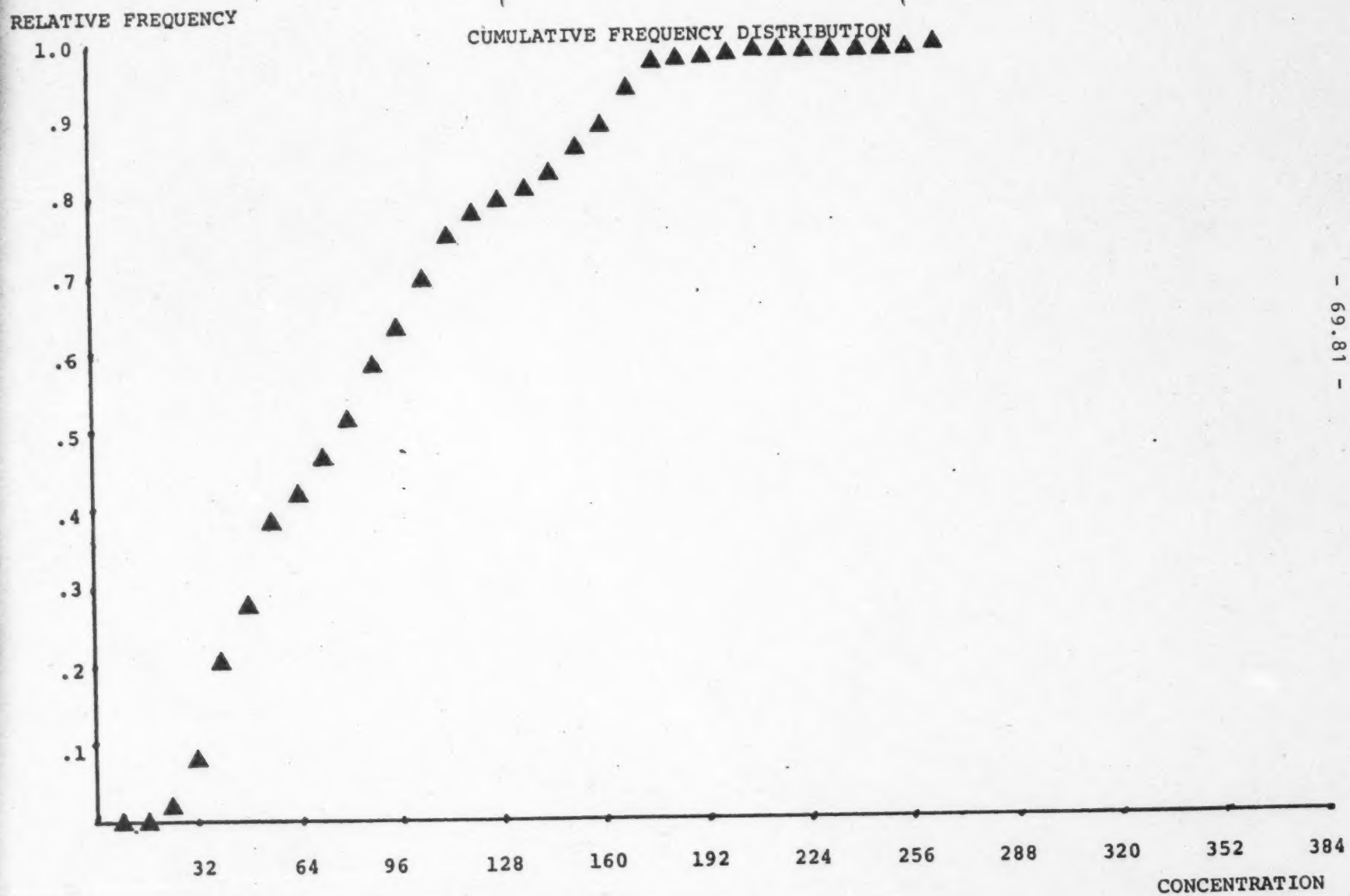
392.00	.99971	.99719
400.00	.99971	.99746



Receptor 4: X=3467.00 KM, Y=5552.00 KM

PREDICTED CONCENTRATION FREQUENCY DISTRIBUTION

TEXAS EPISODIC MODEL CONCENTRATION PREDICTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

PREDICTED CONCENTRATIONS FOR WIND SECTORS 1-16 (MICROGRAMS/CUBIC METER):RECEPTOR 5, AT X=3470.00, Y=5557.00

STABILITY CLASS	WIND SPEED CLASS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1	4.6	2.7	3.2	8.1	7.2	7.4	9.9	7.5	6.4	13.7	8.6	6.2	6.9	6.0	3.8	3.1
A	2	2.8	1.6	2.0	5.0	4.5	4.8	6.3	4.7	4.0	9.3	5.5	3.8	4.2	3.7	2.3	1.9
A	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	1	5.4	3.9	3.3	32.5	9.9	9.7	27.4	19.5	19.5	47.9	11.6	6.9	12.7	8.5	3.9	3.2
B	2	3.3	2.5	2.0	23.9	6.4	6.5	18.6	13.3	12.9	34.5	7.8	4.3	8.0	5.3	2.4	2.0
B	3	1.9	1.4	1.1	14.7	3.7	3.8	11.0	7.8	7.6	21.3	4.6	2.4	4.5	3.0	1.3	1.1
B	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
C	1	8.1	6.2	4.1	42.3	17.1	19.7	72.3	31.2	34.4	98.2	14.4	9.7	23.9	13.3	5.4	4.2
C	2	5.0	3.9	2.5	41.2	10.8	12.8	50.2	24.2	23.2	76.5	9.3	6.0	15.4	8.4	3.3	2.6
C	3	2.8	2.2	1.4	30.9	6.1	7.4	30.0	15.3	13.6	48.7	5.3	3.3	8.8	4.7	1.8	1.4
C	4	1.8	1.4	.9	22.2	4.0	4.9	20.0	10.4	9.0	33.1	3.5	2.1	5.7	3.1	1.2	.9
C	5	1.3	1.1	.6	16.8	2.9	3.6	14.6	7.7	6.6	24.5	2.5	1.5	4.2	2.2	.8	.7
C	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DD	1	16.2	13.0	7.3	39.5	36.6	43.4	73.6	28.1	23.1	77.3	27.8	18.6	37.9	19.9	10.4	7.5
DD	2	10.1	8.5	4.5	32.1	24.1	28.8	76.9	21.5	19.1	73.3	17.7	11.4	27.3	12.7	6.4	4.6
DD	3	5.6	4.9	2.5	24.1	14.0	16.8	63.0	19.3	13.4	59.2	10.1	6.3	17.3	7.4	3.5	2.5
DD	4	3.7	3.2	1.6	22.3	9.2	11.1	48.1	16.2	9.5	46.3	6.6	4.1	11.8	4.9	2.3	1.6
DD	5	2.6	2.3	1.1	18.5	6.7	8.1	37.5	13.3	7.2	36.9	4.8	2.9	8.8	3.5	1.6	1.2
DD	6	2.0	1.8	.9	16.5	5.2	6.3	30.2	11.1	5.7	30.1	3.7	2.2	6.8	2.7	1.2	.9
DN	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	1	25.9	17.2	11.7	67.7	55.4	63.7	102.9	42.5	19.9	92.7	45.4	33.5	45.0	31.8	18.7	11.7
EF	2	16.0	11.1	7.1	45.1	35.4	40.2	73.0	29.6	12.8	68.3	28.1	20.4	28.2	19.5	11.4	7.1
EF	3	8.9	6.4	3.9	27.4	20.4	22.9	50.2	18.9	7.5	44.2	15.7	11.2	16.9	10.8	6.3	3.9
EF	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N

STANDARD STATISTICAL PARAMETERS FOR DISTRIBUTION: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 5, AT X=3470.00 KM, Y=5557.00 KM. CONCENTRATIONS IN MICROGRAMS PER CUBIC METER

ARITHMETIC MEAN CONCENTRATION = 23.22 ARITHMETIC STANDARD DEVIATION = 23.45

GEOMETRIC MEAN CONCENTRATION = 13.76 GEOMETRIC STANDARD DEVIATION = 2.91

PREDICTED 2ND HIGHEST CONCENTRATION FOR YEAR = 228.62. RELATIVE FREQUENCY OF OCCURRENCE OF ZERO CONCENTRATION = .0000

PARAMETERS DERIVED FROM ARITHMETIC MEAN AND STANDARD DEVIATION ASSUMING LOGNORMALITY (AFTER LARSEN):

GEOMETRIC MEAN CONCENTRATION = 16.34
GEOMETRIC STANDARD DEVIATION = 2.31
2ND-HIGH 24-HR CONCENTRATION = 148.22

LOGNORMAL DISTRIBUTION DERIVED FROM NORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY FAILED.

LOGNORMAL DISTRIBUTION:

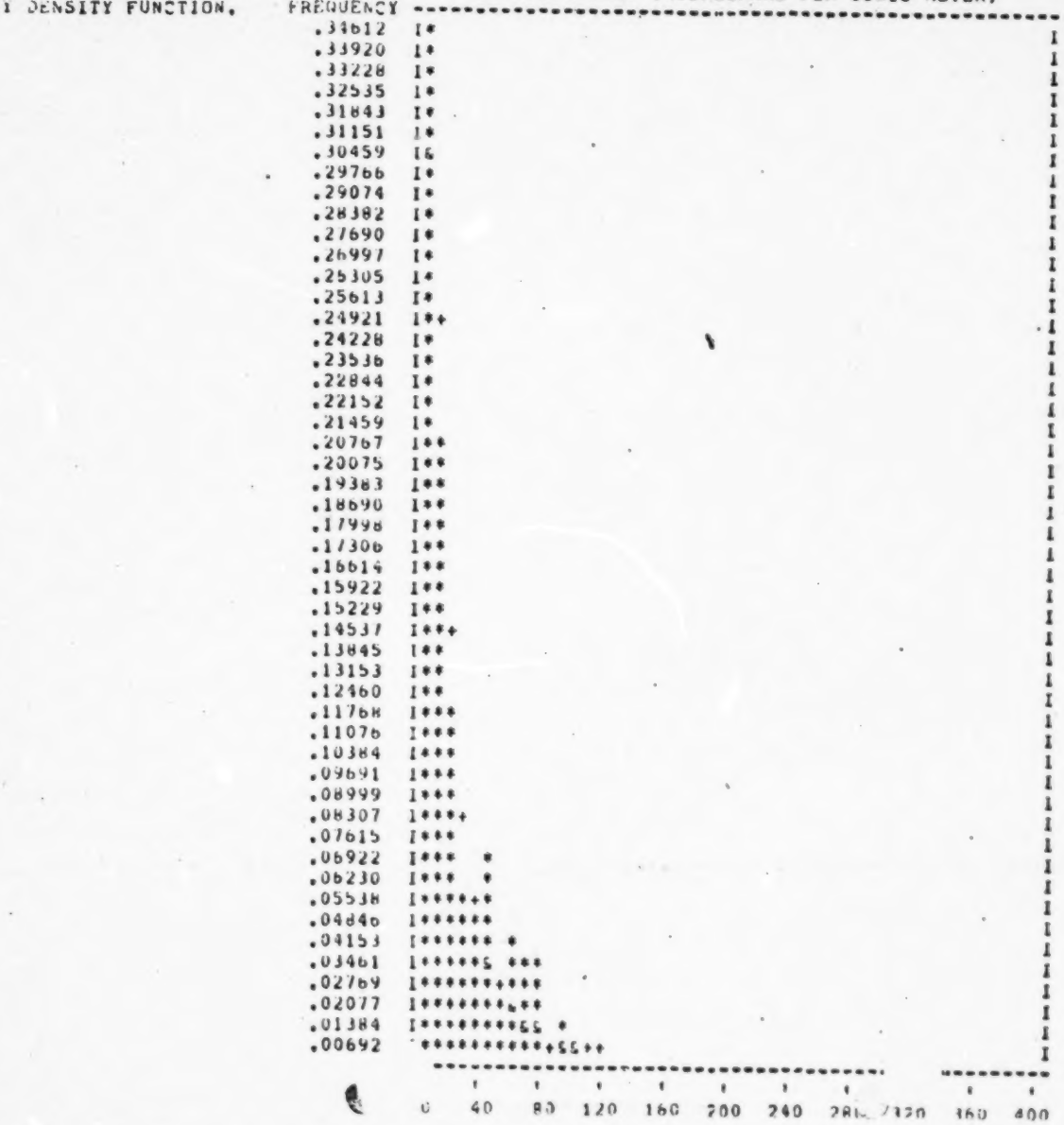
KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

NATDACCPS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 5 AT X=3470.00 KM, Y=5557.00 KM.

HISTOGRAM OF PREDICTED PROBABILITY DENSITY FUNCTION.

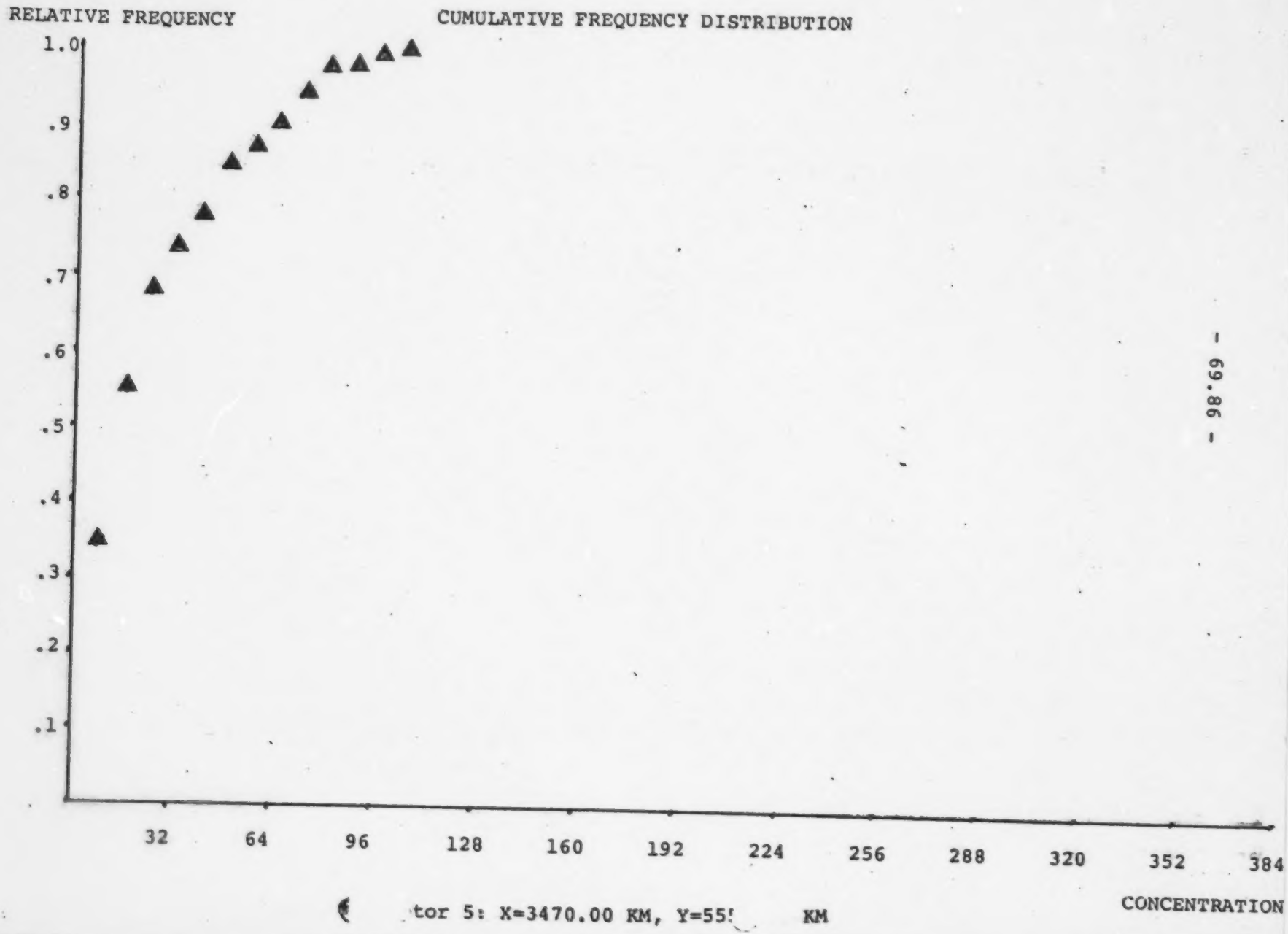
& = COINCIDENCE OF (*) AND (+).
* = PREDICTED PROBABILITY DENSITY FN.
+ = LOGNORMAL FIT TO PREDICTIONS.



PREDICTED CUMULATIVE FREQUENCY DISTRIBUTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 5 AT X=3470.00 KM, Y=5557.00 KM.

CONCENTRATION LEVEL (MICROGRAMS PER CUBIC METER)	PREDICTED FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL	FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL FOR A LOGNORMAL DELTA DISTRIBUTION FIT TO THE DATA
8.00	.34612	.30595
16.00	.55702	.55617
24.00	.67411	.69872
32.00	.73089	.78521
40.00	.77691	.84104
48.00	.84484	.87887
56.00	.86449	.90551
64.00	.90811	.92486
72.00	.94528	.93928
80.00	.97646	.95026
88.00	.97646	.95877
96.00	.99085	.96547
104.00	.99971	.97082
112.00	.99971	.97513
120.00	.99971	.97866
128.00	.99971	.98157
136.00	.99971	.98398
144.00	.99971	.98601
152.00	.99971	.98771
160.00	.99971	.98916
168.00	.99971	.99040
176.00	.99971	.99147
184.00	.99971	.99238
192.00	.99971	.99318
200.00	.99971	.99387
208.00	.99971	.99448
216.00	.99971	.99501
224.00	.99971	.99548
232.00	.99971	.99590
240.00	.99971	.99627
248.00	.99971	.99660
256.00	.99971	.99689
264.00	.99971	.99715
272.00	.99971	.99739
280.00	.99971	.99760
288.00	.99971	.99779
296.00	.99971	.99796
304.00	.99971	.99811
312.00	.99971	.99826
320.00	.99971	.99838
328.00	.99971	.99850
336.00	.99971	.99861
344.00	.99971	.99870
352.00	.99971	.99879
360.00	.99971	.99887
368.00	.99971	.99895
376.00	.99971	.99902
384.00	.99971	.99908
392.00	.99971	.99914
400.00	.99971	.99919


RELATIVE FREQUENCY
CUMULATIVE FREQUENCY DISTRIBUTION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
32
64
96
128
160
192
224
256
288
320
352
384
CONCENTRATION
tor 5: X=3470.00 KM, Y=55
KM

PREDICTED CONCENTRATION FREQUENCY DISTRIBUTION

TEXAS EPISODIC MODEL CONCENTRATION PREDICTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

PREDICTED CONCENTRATIONS FOR WIND SECTORS 1-16 (MICROGRAMS/CUBIC METER):RECEPTOR 6, AT X=3485.00, Y=5552.00

STABILITY CLASS	WIND SPEED CLASS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	1	42.0	43.5	45.3	38.9	36.2	33.8	38.4	43.6	42.7	45.1	49.4	49.4	57.9	159.1	123.0	49.0
A	2	25.8	26.8	27.9	23.9	22.5	20.7	23.4	26.6	26.1	27.6	30.2	30.8	37.5	114.6	84.7	30.2
A	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
A	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	1	43.4	44.7	48.6	44.7	44.7	34.9	38.4	43.6	42.5	49.4	53.7	54.8	70.8	85.0	130.6	48.9
B	2	27.2	28.1	30.7	28.6	28.7	21.6	23.4	26.6	26.0	30.8	33.1	35.0	45.8	66.2	94.5	30.8
B	3	15.2	15.8	17.3	16.2	16.4	12.0	12.9	14.6	14.3	17.2	18.4	20.1	26.4	48.4	59.1	17.4
B	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
B	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
C	1	47.8	46.3	54.4	51.9	54.8	34.8	43.3	52.2	49.2	59.5	66.2	82.5	133.3	73.0	121.5	52.4
C	2	30.2	29.0	34.7	35.5	36.2	21.3	26.4	31.8	30.0	37.9	42.3	54.9	87.7	48.4	94.6	32.5
C	3	17.2	16.3	19.8	21.1	21.0	11.8	14.5	17.5	16.5	21.6	23.6	32.2	50.8	28.9	52.3	16.1
C	4	11.2	10.6	12.9	14.1	13.8	7.6	9.4	11.3	10.7	14.1	15.3	21.4	33.5	19.7	43.4	11.7
C	5	8.1	7.7	9.4	10.3	10.1	5.5	6.8	8.1	7.7	10.3	11.1	15.6	24.4	14.7	32.5	8.5
C	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DD	1	66.8	62.5	74.8	63.3	53.6	41.7	62.2	82.1	75.3	86.4	109.6	130.9	189.6	97.5	98.2	75.5
DD	2	41.0	38.3	47.1	46.4	35.5	25.5	37.9	50.1	45.9	54.9	68.7	93.8	151.0	61.2	69.0	46.3
DD	3	22.9	21.1	26.7	31.1	21.2	14.1	20.9	27.6	25.3	31.5	38.6	62.3	102.4	34.5	45.1	25.6
DD	4	14.9	13.7	17.4	22.0	14.4	9.1	13.5	17.8	16.3	20.9	25.2	44.9	72.3	22.5	32.1	16.6
DD	5	10.8	9.9	12.7	16.6	10.6	6.5	9.7	12.8	11.8	15.3	18.2	34.6	54.4	16.4	24.4	12.0
DD	6	8.3	7.6	9.8	13.1	8.3	5.0	7.5	9.8	9.0	11.8	14.0	27.6	42.8	12.6	19.4	9.2
DN	1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
DN	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	1	81.0	71.3	87.1	63.7	41.6	31.0	71.0	110.6	96.9	112.8	145.8	203.6	229.7	128.8	112.3	98.0
EF	2	49.4	43.5	53.7	39.7	26.2	18.9	43.3	67.4	59.1	69.6	89.7	134.6	151.8	79.3	69.6	59.6
EF	3	27.2	23.9	29.9	22.7	14.9	10.4	23.8	37.1	32.5	38.7	49.8	79.8	91.6	44.1	39.0	33.0
EF	4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
EF	6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0

- 69.87 -

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N

STANDARD STATISTICAL PARAMETERS FOR DISTRIBUTION: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 6, AT X=3485.00 KM, Y=5552.00 KM. CONCENTRATIONS IN MICROGRAMS PER CUBIC METER

ARITHMETIC MEAN CONCENTRATION = 50.69 ARITHMETIC STANDARD DEVIATION = 29.95

GEOMETRIC MEAN CONCENTRATION = 42.91 GEOMETRIC STANDARD DEVIATION = 1.81

PREDICTED 2ND HIGHEST CONCENTRATION FOR YEAR = 204.01. RELATIVE FREQUENCY OF OCCURRENCE OF ZERO CONCENTRATION = .0000

PARAMETERS DERIVED FROM ARITHMETIC MEAN AND STANDARD DEVIATION ASSUMING LOGNORMALITY (AFTER LARSEN):

GEOMETRIC MEAN CONCENTRATION = 43.64
GEOMETRIC STANDARD DEVIATION = 1.73
2ND-HIGH 24-HR CONCENTRATION = 184.05

LOGNORMAL DISTRIBUTION DERIVED FROM NORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

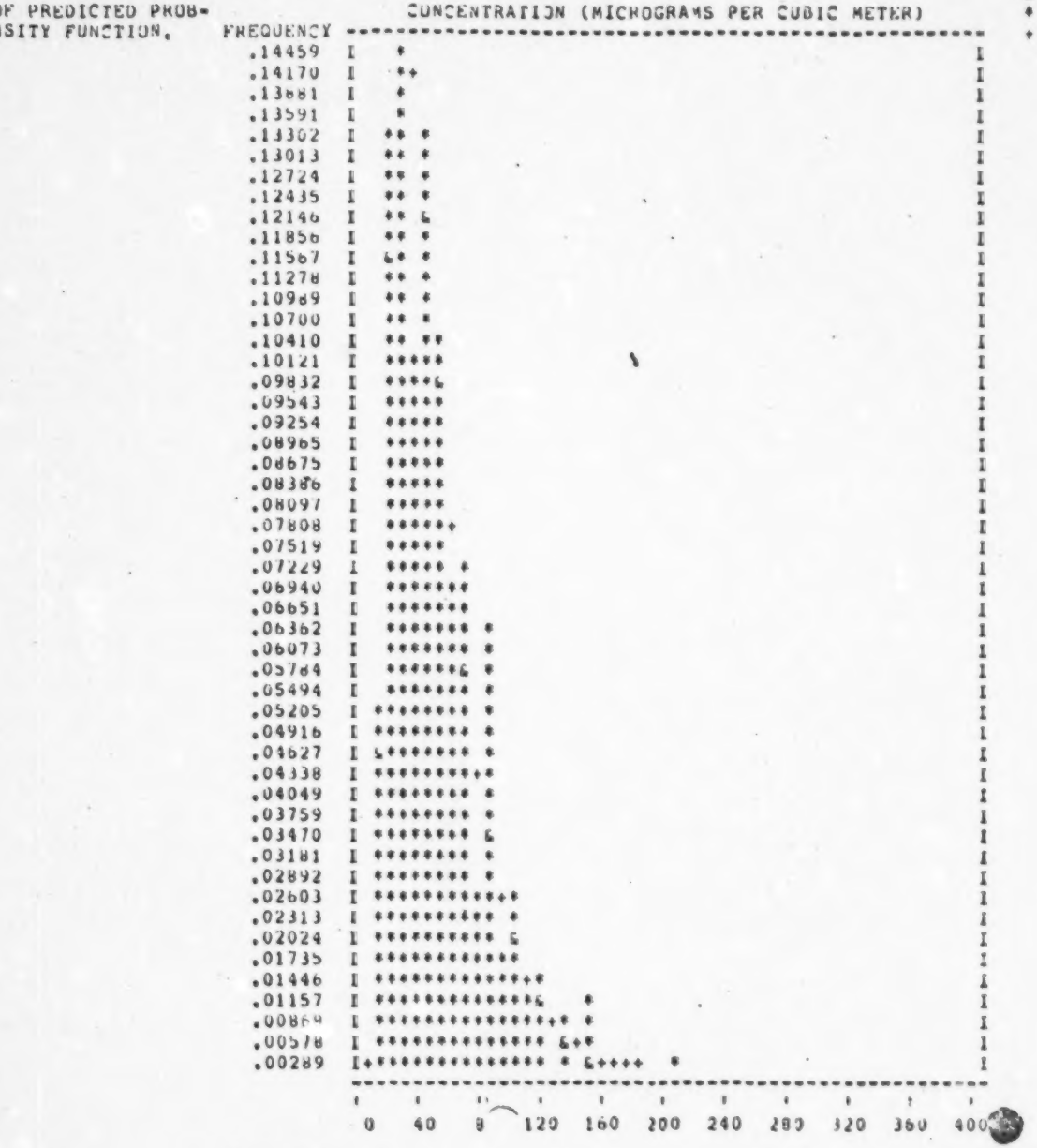
LOGNORMAL DISTRIBUTION:

KOLMOGOROV-SMIRNOV TEST FOR LOGNORMALITY PASSED AT SIGNIFICANCE LEVELS: .01 .10 .15 .20

NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 6 AT X=3465.00 KM, Y=5552.00 KM.
& = COINCIDENCE OF (*) AND (+).
* = PREDICTED PROBABILITY DENSITY FN.
+ = LOGNORMAL FIT TO PREDICTIONS.

HISTOGRAM OF PREDICTED PROBABILITY DENSITY FUNCTION.



PREDICTED CUMULATIVE FREQUENCY DISTRIBUTIONS: NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6.

RECEPTOR 6 AT X=3485.00 KM, Y=5552.00 KM.

CONCENTRATION LEVEL (MICROGRAMS PER CUBIC METER)	PREDICTED FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL	FREQUENCY OF CONCENTRATIONS BELOW THE SPECIFIED LEVEL FOR A LOGNORMAL DELTA DISTRIBUTION FIT TO THE DATA
8.00	.00000	.00230
16.00	.05277	.04802
24.00	.18494	.16345
32.00	.32953	.31028
40.00	.43200	.45279
48.00	.56537	.57494
56.00	.67015	.67329
64.00	.74022	.74993
72.00	.81282	.80866
80.00	.83855	.85331
88.00	.90280	.88715
96.00	.91968	.91281
104.00	.94711	.93232
112.00	.95900	.94721
120.00	.97459	.95861
128.00	.97526	.96738
136.00	.98385	.97417
144.00	.98385	.97944
152.00	.99532	.98356
160.00	.99532	.98679
168.00	.99532	.98934
176.00	.99532	.99136
184.00	.99532	.99297
192.00	.99654	.99426
200.00	.99654	.99529
208.00	.99869	.99612
216.00	.99869	.99680
224.00	.99869	.99735
232.00	.99971	.99779
240.00	.99971	.99816
248.00	.99971	.99846
256.00	.99971	.99871
264.00	.99971	.99891
272.00	.99971	.99908
280.00	.99971	.99922
288.00	.99971	.99934
296.00	.99971	.99944
304.00	.99971	.99952
312.00	.99971	.99959
320.00	.99971	.99965
328.00	.99971	.99970
336.00	.99971	.99974
344.00	.99971	.99978
352.00	.99971	.99981
360.00	.99971	.99983
368.00	.99971	.99986
376.00	99971	.99987
384.00	99971	.99989
392.00	99971	.99990
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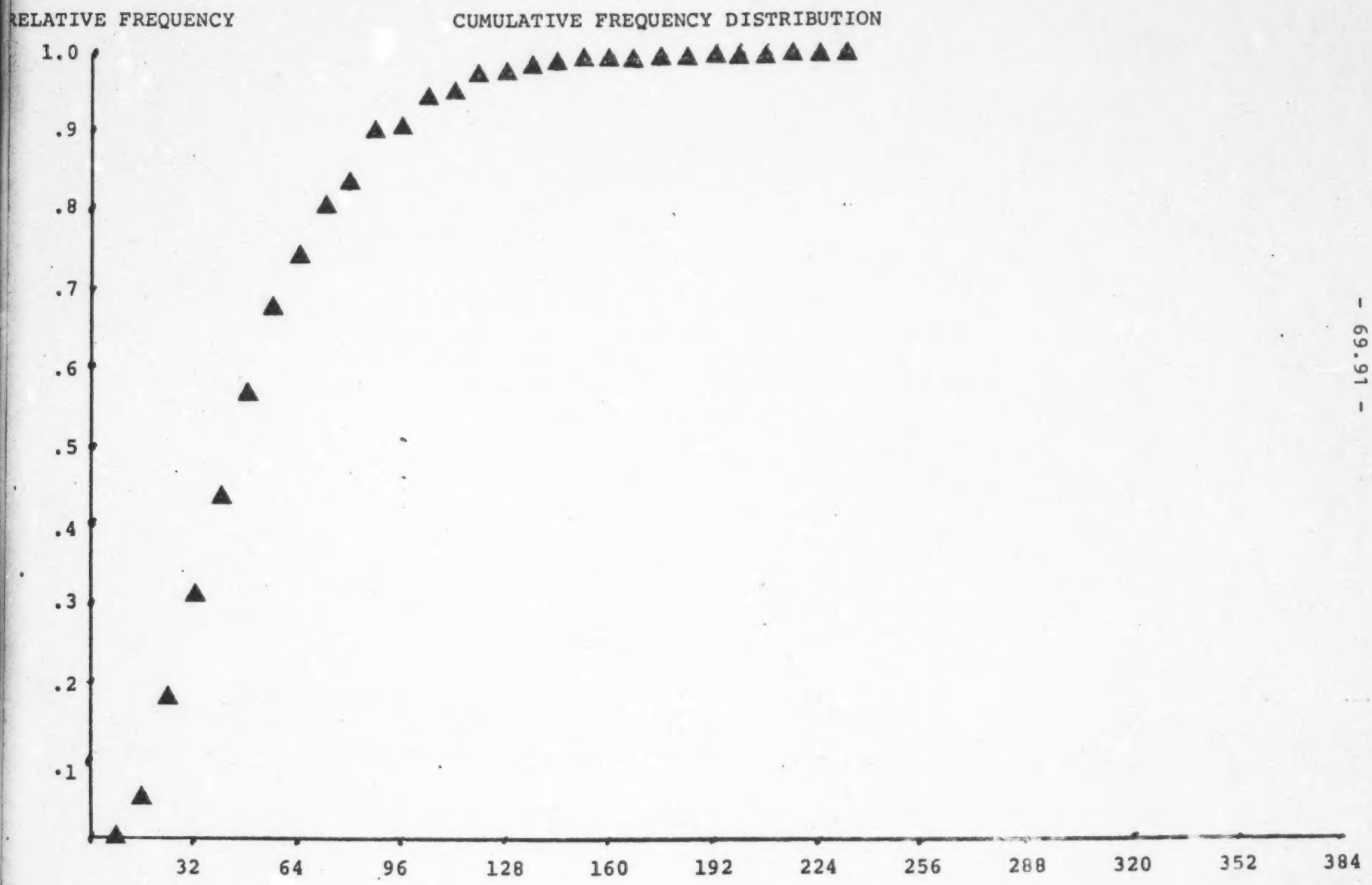

Receptor 6: X=3485.00 KM, Y=5552.00 KM

P R E D I C T E D C O N C E N T R A T I O N F R E Q U E N C Y D I S T R I B U T I O N - S U M M A R Y R E P O R T

NATO/CCMS STUDY: FRANKFURT AM MAIN ANNUAL SULFUR DIOXIDE, TEST RECEPTORS 1 TO 6. / FRANKFT6

RECEPTOR NUMBER	X (KM)	Y (KM)	ARITHMETIC MEAN CONC.	NORM. ARITH. STD. DEV.	GEOMETRIC MEAN CONC.	GEO. STD. DEV.	2ND HIGH (LN FIT)	2ND HIGH (LARSEN)	CONC. (RATIONS AT SPECIFIED CUMULATIVE FREQUENCY LEVELS: 60.0%	95.0%	97.5%
1	3473.29	5551.53	122.82	.57	103.15	1.87	533.37	427.13	127.3	258.6	288.2
2	3479.25	5553.15	96.69	.56	82.73	1.78	376.65	332.19	102.5	206.5	220.4
3	3475.76	5553.98	111.00	.65	91.73	1.89	487.00	440.90	110.6	253.2	323.3
4	3467.00	5552.00	85.13	.59	71.36	1.85	359.82	307.94	90.7	168.8	193.0
5	3470.00	5557.00	23.22	1.01	13.76	2.91	228.62	148.22	18.9	73.2	79.6
6	3485.00	5552.00	50.69	.59	42.91	1.81	204.01	184.05	50.6	105.9	124.9

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Turner; USA

NATO/CCMS PANEL ON MODELING

Documentation for Practical Demonstration

of Urban Air Quality Simulation Models

THE APPLICATION OF THE CDM (CLIMATOLOGICAL DISPERSION MODEL) TO THE NATO COMMON DATA BASE FOR FRANKFURT

NOTICE - This document is a draft. It has not been formally released by NOAA or EPA and should not be considered to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

by

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Research Triangle Park, North Carolina 27711

This paper is one of two prepared by the Meteorology and Assessment Division on results of the demonstration exercise. The other paper is:

The Application of the SCAM (Sampled Chronological Air-Quality Model) to the NATO Common Data Base for Frankfurt by John S. Irwin.

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*On Assignment from the National Oceanic and Atmospheric Administration, Department of Commerce

THE APPLICATION OF THE CDM (CLIMATOLOGICAL DISPERSION MODEL) TO THE NATO COMMON DATA BASE FOR FRANKFURT

by D. Bruce Turner

Using the joint frequency tables of wind speed, direction, and stability class received from Dr. Dieter Jost, Chairman, NATO/CCMS Panel on Modeling, a joint frequency distribution for 36 compass points was produced by Mr. John Irwin having the same six wind speed classes as used by the original CDM. This information is for the entire one year period to be modeled August 1, 1971 to July 31, 1972. (It was our intent to model the period seasonally so that the emissions from space heating could be varied with none in summer, some in spring and fall, and higher values in winter. However, joint frequency information was not available for an averaging time shorter than the one year period and the seasonal modeling was therefore not possible.)

Mr. Richard Porter and Mr. John Christiansen of the Texas Air Control Board formed a 16 point joint frequency distribution from the 36 point distribution furnished by Mr. Irwin and sent a card deck to us. Since this information was available, we therefore applied on the annual basis, both the original CDM (Busse and Zimmerman, 1973) utilizing the 16-point joint frequency information and the CDM 36 (Turner, 1976) using the 36-point joint frequency information. The resulting concentrations were similar.

The emission inventory of point sources was received in the form of tabulations, and the area sources in the form of a map. A card deck for the point sources was keypunched directly from the tabulations, and then checked

by Mr. Irwin. The area source data were coded by Mr. Turner and Mr. Irwin working from the map and a correction sheet. The coded forms were sent for keypunching and the resulting area source card deck checked. Copies of these decks were also furnished to the other U.S. participants. There were 1457 area sources and 679 point sources in the emission inventory. Annual average point source emissions were reported in kilograms per hour. These were converted to grams per second for input to the models. Area source emissions were reported in kilograms of SO_2 per hour of heating. It was stated that there were 1560 hours of heating during the year. The annual emission in grams SO_2 per area source, 500 meters on a side, was thus 1560 times 1000 g kg^{-1} times the reported value for the area source. The mean annual emissions in g $sec^{-1}m^{-2}$ for this square is the above value divided by 250000 m^2 and divided by the number of seconds in a year (8760 hours times 3600 sec per hour).

Several assumptions were made regarding some of the inputs to the CDM. In the absence of data on the mean annual mixing height, a mean height of 5000 meters for the tropopause was used. A mean annual temperature of 9.7°C was used for Frankfurt. An exponential decay rate for the SO_2 was also assumed corresponding to a half-life of 3 hours. CDM allows different emission rates during daytime and nighttime. As no specific information on variability of SO_2 emissions in Frankfurt was available, no variation was assumed; the mean annual emission rate for each source was assumed for both day and night. To account for increased turbulence due to mechanical mixing over the roughness elements of the city and also the release of urban heat, an initial σ_z of 30 meters was used for all stability classes.

The resulting concentration estimates at the six receptor locations from CDM and from CDM 36, are given in the following table. If there are general background levels of SO_2 entering the Frankfurt area due to sources outside the region considered in the emission inventory, the annual average of this background concentration should be added to the concentrations resulting from the model calculations, before comparing with the measured values.

Measured concentrations for these six locations will be made available by Dr. Dieter Jost when all calculated concentrations are received from participants of the modeling exercise.

Table 1

Receptor Coordinates		Annual Average Sulfur Dioxide Concentrations for Frankfurt, $\mu g\ m^{-3}$	
East	North	CDM	CDM 36
22.29	26.53	68	71
28.25	28.15	59	60
24.76	28.98	71	76
16.00	27.00	50	53
19.00	32.00	29	30
34.00	27.00	35	37

A useful feature of the CDM models is that a pollution rose (indicating the contribution to the total concentration from both the point and area sources, by direction) is available as an option. These pollution roses were determined for the six receptor locations for which calculations were made. The roses break the total concentration at a receptor into 72 components (corresponding to 36 directions and two source types), and are given in Table 2. The computer run required to perform the annual average concentration estimates for the six locations, including the pollution roses, required 1 minute 43 seconds on the UNIVAC 1110 for an approximate cost of $6.70. The run for six stations using the original CDM utilizing 16 point frequencies required 1 minute 10 seconds on the UNIVAC 1110 for an approximate cost of $4.54.

In order to provide sufficient information so that the annual average sulfur dioxide pattern over Frankfurt could be determined, a second run of CDM 36 was made for an additional 45 selected locations. This resulted in covering the 19 km. by 10 km. area for which isolines of concentration were desired with sampling stations approximately 3 km. apart. The concentrations for these 45 locations and also the original six locations are plotted in Figure 1. Lines of equal concentration with an interval of 10 μgm^{-3} have been drawn in Figure 1. This was the result of a hand analysis of the concentration field. Pollutant roses were not obtained for these 45 locations. The computer run required 7 minutes 4 seconds on the UNIVAC 1110 for an estimated cost of $28.38.

ACKNOWLEDGEMENTS

The author is grateful to John Irwin for his many hours of preparation of the data base; to Richard Porter and John Christiansen for their furnishing the 16-point stability wind frequencies; to Joan Novak, Cynthia Joyner, Ginger Smiley, and Alan Cope for their computer assistance; and to Lea Prince and Pat Smith for their assistance in preparing the manuscript.

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Busse, Adrian D.; and Zimmerman, John R., 1973: User's Guide for the Climatological Dispersion Model. Environmental Protection Agency. Environmental Monitoring Series EPA-R4-73-024. Research Triangle Park, NC 27711, December 1973.

Turner, D. Bruce, 1976: A Climatological Dispersion Model for 10° Wind Sectors (CDM 36). Documentation for Practical Demonstration of Urban Air Quality Simulation Models. Submitted to NATO/CCMS Panel on Modeling. March, 1976.

TABLE 2. (PART ONE OF THREE)

FRANKFURT SO_2 POLLUTION ROSES

(CONCENTRATIONS IN $\mu g\ m^{-3}$)

Receptor Coordinates

22.29 26.53

SECT.	NO.*	AREA	POINT	TOTAL
1	14	1.47	.48	1.30
2	8	3.01	.08	3.10
3	8	3.88	.12	4.00
4	28	4.04	1.14	5.09
5	21	3.12	.87	3.99
6	42	7.11	1.31	8.41
7	65	3.16	1.22	4.38
8	95	2.36	.88	2.31
9	57	1.32	3.05	4.37
10	35	.89	.32	1.21
11	1	.32	.01	.33
12	2	.43	.00	.43
13	8	.44	.00	.44
14	6	.31	.02	.33
15	16	.27	.01	.29
16	13	.35	.04	.39
17	11	.47	.08	.55
18	13	.37	.05	.32
19	1	1.58	.02	1.59
20	2	1.68	.08	1.75
21	4	1.88	.28	2.00
22	2	1.76	.02	1.80
23	28	1.67	.94	2.61
24	26	1.33	2.17	3.50
25	15	.38	.06	1.54
26	14	.70	2.03	2.73
27	16	.06	.27	.37
28	14	.29	.01	.30
29	8	.19	.11	.30
30	12	.24	.04	.28
31	19	.26	.20	.46
32	25	.33	.06	.39
33	7	.31	.02	.33
34	14	.32	.01	.33
35	8	.36	.02	.37
36	32	.65	.13	.78
TOTAL		54.55	16.56	71.11

* NUMBER OF POINT SOURCES THIS SECTOR.

Receptor Coordinates

28.25 28.15

SECT.	NO.*	AREA	POINT	TOTAL
1	2	1.87	.02	1.89
2	2	2.33	.06	2.39
3	11	2.84	.17	3.01
4	13	3.22	.47	3.69
5	9	2.74	.25	2.99
6	4	2.31	.67	2.98
7	13	1.51	.98	2.49
8	43	1.02	.35	1.38
9	31	1.28	.06	1.38
10	32	1.16	1.18	2.34
11	15	.74	.16	.90
12	18	.46	.07	.53
13	18	.27	.04	.31
14	8	.13	.01	.14
15	5	.11	.02	.13
16	4	.11	.06	.17
17	2	.18	.05	.23
18	7	.04	.01	.05
19	40	1.00	.22	1.23
20	14	1.03	.47	1.50
21	9	1.84	2.16	3.99
22	8	2.79	.14	2.93
23	17	2.85	.15	3.00
24	46	2.07	2.01	4.08
25	43	1.36	3.03	4.39
26	55	1.13	1.04	2.23
27	46	.37	.02	1.40
28	59	.76	.20	.91
29	35	.44	.05	.50
30	13	.64	.02	.67
31	17	.31	.05	.36
32	13	.95	.28	1.23
33	27	.96	.04	1.01
34	11	.58	.01	.59
35	5	.55	.07	.62
36	8	1.17	.00	1.17
TOTAL		45.01	14.71	59.72

* NUMBER OF POINT SOURCES THIS SECTO

TABLE 2. (PART TWO OF THREE)

FRANKFURT SO_2 POLLUTION ROSES

(CONCENTRATIONS IN $\mu g\ m^{-3}$)

Receptor Coordinates

24.76 28.98

SECT.	NO.*	AREA	POINT	TOTAL
1	2	1.10	.06	1.10
2	0	2.13	.00	2.13
3	3	2.76	.02	2.78
4	4	3.33	.07	4.21
5	1	5.67	.00	5.00
6	5	6.24	.30	6.61
7	20	4.76	.29	5.05
8	33	3.92	.15	4.05
9	65	3.16	.00	3.76
10	59	2.31	.08	3.19
11	30	1.31	.08	1.70
12	24	.90	.12	1.01
13	15	.60	.09	.98
14	18	.40	.21	.61
15	10	.46	.04	.50
16	10	.62	.07	.69
17	29	.61	.05	.66
18	21	1.14	.16	1.30
19	17	2.01	2.05	4.06
20	8	1.96	.25	2.20
21	13	2.44	1.54	3.97
22	13	2.92	.57	3.39
23	43	2.10	2.42	4.52
24	37	1.30	2.34	3.65
25	38	1.20	1.89	3.09
26	21	.92	.09	1.01
27	18	.72	.05	.77
28	18	.45	.03	.47
29	29	.24	.06	.29
30	6	.28	.50	.77
31	6	.26	.01	.28
32	11	.35	.02	.37
33	10	.27	.03	.30
34	15	.27	.09	.36
35	12	.28	.07	.35
36	11	.66	.03	.69
TOTAL		60.35	15.90	76.25

* NUMBER OF POINT SOURCES THIS SECTOR.

Receptor Coordinates

16.00 27.00

SECT.	NO.*	AREA	POINT	TOTAL
1	11	1.03	.06	1.09
2	30	1.68	.20	1.88
3	13	2.50	.10	2.59
4	15	4.24	.44	4.69
5	14	4.51	1.32	5.82
6	17	4.76	.12	4.88
7	31	4.00	.12	4.10
8	152	2.49	.38	2.87
9	146	2.38	2.30	4.67
10	38	1.62	.11	1.73
11	11	.87	.88	1.75
12	29	.53	.04	.57
13	11	.25	.00	.25
14	6	.15	.01	.16
15	10	.17	.08	.25
16	9	.20	.02	.22
17	6	.30	.01	.30
18	0	.37	.00	.37
19	4	.47	.06	1.14
20	4	.62	.77	1.39
21	29	.96	4.42	3.38
22	20	.80	1.59	2.39
23	13	.44	.16	.59
24	2	.57	.02	.59
25	10	.49	.07	.56
26	4	.25	.00	.25
27	1	.22	.00	.22
28	4	.14	.00	.15
29	3	.13	.00	.13
30	1	.18	.00	.18
31	2	.23	.05	.28
32	1	.27	.00	.27
33	16	.26	.10	.36
34	6	.21	.01	.22
35	3	.24	.08	.31
36	7	.54	.01	.56
TOTAL		39.12	14.11	53.23

* NUMBER OF POINT SOURCES THIS SECTO

TABLE 2. (PART THREE OF THREE)

FRANKFURT SO_2 POLLUTION ROSES

(CONCENTRATIONS IN $\mu g\ m^{-3}$)

Receptor Coordinates

19.00 32.00

SECT.	NO.*	AREA	POINT	TOTAL
1	13	.26	.15	.41
2	17	.18	.23	.41
3	3	.11	.01	.12
4	1	.03	.01	.03
5	5	1.15	.04	1.19
6	6	1.37	.00	1.37
7	9	1.33	.07	2.30
8	1	.37	.00	1.03
9	40	1.23	.20	1.43
10	83	1.36	.02	1.38
11	54	.77	.01	.38
12	77	.34	.00	.38
13	42	.33	.00	.32
14	28	.13	.27	.40
15	57	.14	.11	.25
16	14	.09	.03	.13
17	21	.09	.04	.93
18	6	.43	.02	.44
19	6	.68	.10	.78
20	13	1.20	1.28	2.54
21	44	1.14	6.00	7.00
22	23	.31	.04	1.34
23	13	.51	.22	.73
24	9	.47	.01	.48
25	4	.46	.01	.48
26	13	.33	.13	.47
27	8	.05	.14	.20
28	2	.03	.01	.04
29	0	.00	.00	.00
30	2	.04	.00	.04
31	1	.02	.00	.03
32	4	.02	.00	.02
33	3	.02	.00	.02
34	2	.04	.00	.04
35	0	.08	.01	.09
36	3	.11	.02	.13
TOTAL		17.18	12.86	30.04

* NUMBER OF POINT SOURCES THIS SECTOR.

Receptor Coordinates

34.00 27.00

SECT.	NO.*	AREA	POINT	TOTAL
1	1	.33	.23	.51
2	1	.47	.00	.47
3	2	.93	.03	1.07
4	2	2.10	.40	2.40
5	3	1.73	.40	1.34
6	2	1.05	.01	1.06
7	35	.73	.03	1.06
8	22	.30	1.13	1.43
9	7	.10	.20	.30
10	5	.13	.03	.41
11	4	.12	.01	.13
12	2	.15	.00	.16
13	2	.17	.00	.17
14	1	.10	.00	.10
15	1	.10	.00	.10
16	0	.14	.00	.14
17	0	.24	.00	.24
18	3	.03	.00	.03
19	0	1.29	.00	1.29
20	15	1.80	.00	2.25
21	13	2.33	.46	2.33
22	20	2.28	.40	2.68
23	20	1.54	.24	1.73
24	23	1.26	.10	1.36
25	48	1.05	1.03	2.08
26	38	1.12	.42	1.54
27	102	.67	1.36	2.03
28	122	.50	.13	.63
29	55	.27	.05	.32
30	23	.26	.37	.64
31	37	.30	.67	.97
32	42	.35	.37	.72
33	13	.25	.06	.31
34	3	.15	.00	.16
35	0	.18	.00	.18
36	1	.21	.00	.21
TOTAL		26.38	10.75	37.13

* NUMBER OF POINT SOURCES THIS SECTO

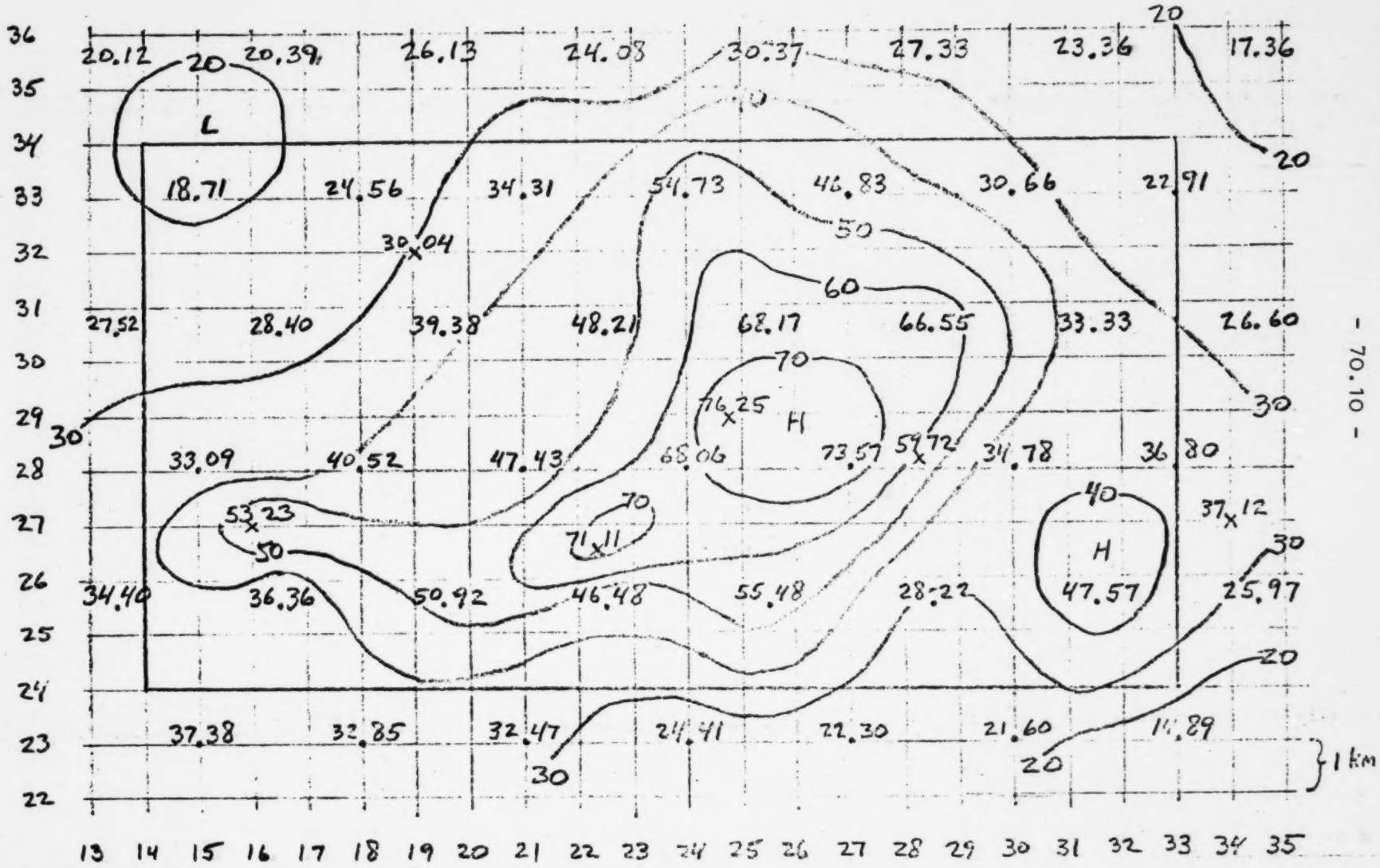

FIGURE 1. ANNUAL SO_2 CONCENTRATION PATTERN in $\mu g\ m^{-3}$ for FRANKFURT, AUGUST 1971 - JULY 1972

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Irwin; USA

NATO/CCMS PANEL ON MODELING

Documentation for Practical Demonstration

Of Urban Air Quality Simulation Models

THE APPLICATION OF THE SCAM (SAMPLED CHRONOLOGICAL AIR-QUALITY MODEL) TO THE NATO COMMON DATA BASE FOR FRANKFURT

NOTICE - This document is a draft. It has not been formally released by NOAA or EPA and should not be considered to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

by

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This paper is one of two prepared by the Meteorology and Assessment Division on results of the demonstration exercise. The other paper is:

The Application of the CDM (Climatological Dispersion Model) to the NATO Common Data Base for Frankfurt by D. Bruce Turner.

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*On Assignment from the National Oceanic and Atmospheric Administration, Department of Commerce

August 1976

THE APPLICATION OF THE SCAM (SAMPLED CLIMATOLOGICAL AIR-QUALITY MODEL) TO THE NATO COMMON DATA BASE FOR FRANKFURT

by John S. Irwin

Using the tabulations received from Dr. Dieter Jost, Chairman, NATO/CCMS Panel on Modeling, computer compatible card decks were generated for the joint-frequency distribution of the meteorological conditions, for the area source emission inventory, and also for the point source emission inventory. The details concerning the procedures used to generate these decks are briefly described by D. B. Turner, 1976.

The application of SCAM requires the same input information as required by CDM (The Climatological Dispersion Model). Since some information was not available assumptions were made so that certain parameters could be specified. These assumptions are similar to those made by D. B. Turner in application of CDM to the Frankfurt data base. Receptor height at the six designated locations was assumed to be zero. A mean height of the tropopause of 5000 meters was used for a limit to vertical mixing. A mean annual temperature for Frankfurt of 9.7°C was used. An exponential decay rate for the SO_2 was also assumed corresponding to a half-life of 3 hours. No initial vertical dispersion, σ_{zo}, was assumed. If there is a background level of SO_2 entering the Frankfurt area from sources outside the region considered in the emission inventory, the annual average of this background concentration of SO_2 should be added to the model estimates before making comparisons with the measured

values. Measured concentrations of SO_2 at the six designated receptor locations will be made available by Dr. Dieter Jost at a later time.

Even though SCAM requires the same input as CDM for application, the analysis performed by SCAM is different. SCAM consist of two preprocessor programs and one main program. One preprocessor program organizes the emission inventory in a suitable fashion for efficient use by the main program. The second preprocessor program uses the joint-frequency function of meteorological parameters to select a sample of meteorological conditions (Irwin, 1976). The sample's characteristics are similar to those of the joint-frequency function of the meteorological parameters and the larger the sample size the greater the similarity. At the present time no definitive criteria have been developed as to the sample size required to insure representative estimates. For the application on the Frankfurt data base, 5 samples of 500 meteorological conditions were selected.

The resulting estimates of annual SO_2 concentration from application of SCAM at the six given receptor locations are shown in Table 1.

The frequency distributions of total SO_2 concentration for the six receptor locations are given in figures 1 through 6. Actually 5 distributions were available for each receptor location. However, the differences between the five distributions due to five meteorological samples was very slight and only one distribution is given for each location. Sample 5 was used for plotting figures 1 through 6. The meteorological conditions which produced

Table 1. Estimates of Annual SO_2 Concentrations at Six Receptor Locations for 5 Samples of 500 Meteorological Conditions.

RECEPTOR NUMBER	RECEPTOR COORDINATES (KM.) EAST	NORTH	SAMPLE	AREA SOURCE CONTRIBUTION ($\mu G/M^3$)	POINT SOURCE CONTRIBUTION ($\mu G/M^3$)	AVERAGE TOTAL CONCENTRATION FOR ALL 5 SAMPLES ($\mu G/M^3$)
			1	67.95	3.696	
			2	68.70	3.692	
1	22.90	26.53	3	69.32	3.734	71.72
			4	66.25	3.594	
			5	67.44	4.225	
			1	53.12	3.505	
			2	52.98	3.466	
2	28.25	28.15	3	54.80	3.608	56.60
			4	51.59	3.504	
			5	52.81	3.635	
			1	72.74	3.530	
			2	71.11	3.652	
3	24.76	28.98	3	73.63	3.440	75.20
			4	70.42	3.406	
			5	70.49	3.620	
			1	44.46	2.959	
			2	44.85	2.527	
4	16.00	27.00	3	45.73	2.761	47.32
			4	42.98	2.568	
			5	44.62	3.125	
			1	20.11	1.913	
			2	18.74	1.888	
5	19.00	32.00	3	19.61	1.806	21.29
			4	19.53	1.951	
			5	18.81	2.115	
			1	35.76	2.491	
			2	34.90	2.504	
6	34.00	27.00	3	36.36	2.331	37.85
			4	35.26	2.224	
			5	35.03	2.422	

the highest values of total SO_2 concentration for the six receptor locations, using meteorological sample 5, are given in Table 2.

ACKNOWLEDGEMENTS

Special thanks are due to Mr. D. B. Turner and Mrs. J. H. Novak who developed the computer algorithms for the Real-Time Air-Quality Model from which the computer algorithms for the Sampled Climatological Air-Quality Model were developed. The author greatly appreciates the hours of cheerful assistance given by Lea Prince in the preparation of the manuscript.

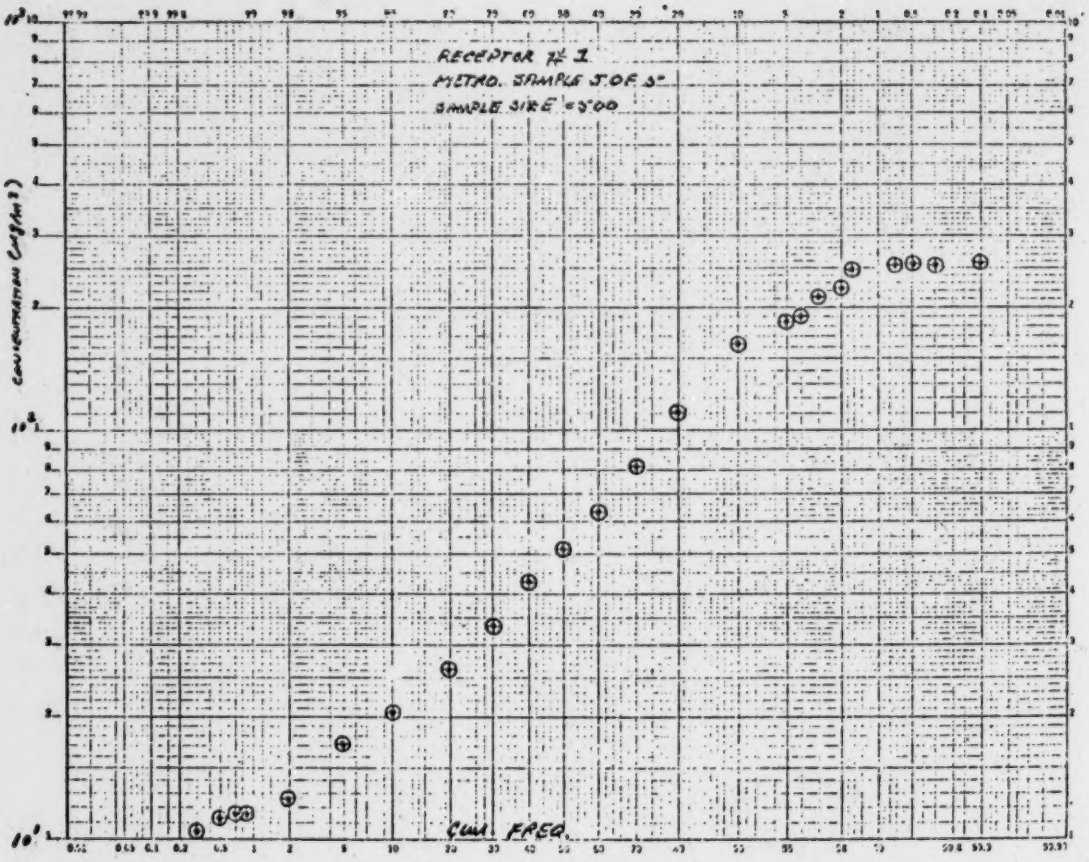

Figure 1. Cumulative Frequency Distribution of Total Concentration for Receptor 1.

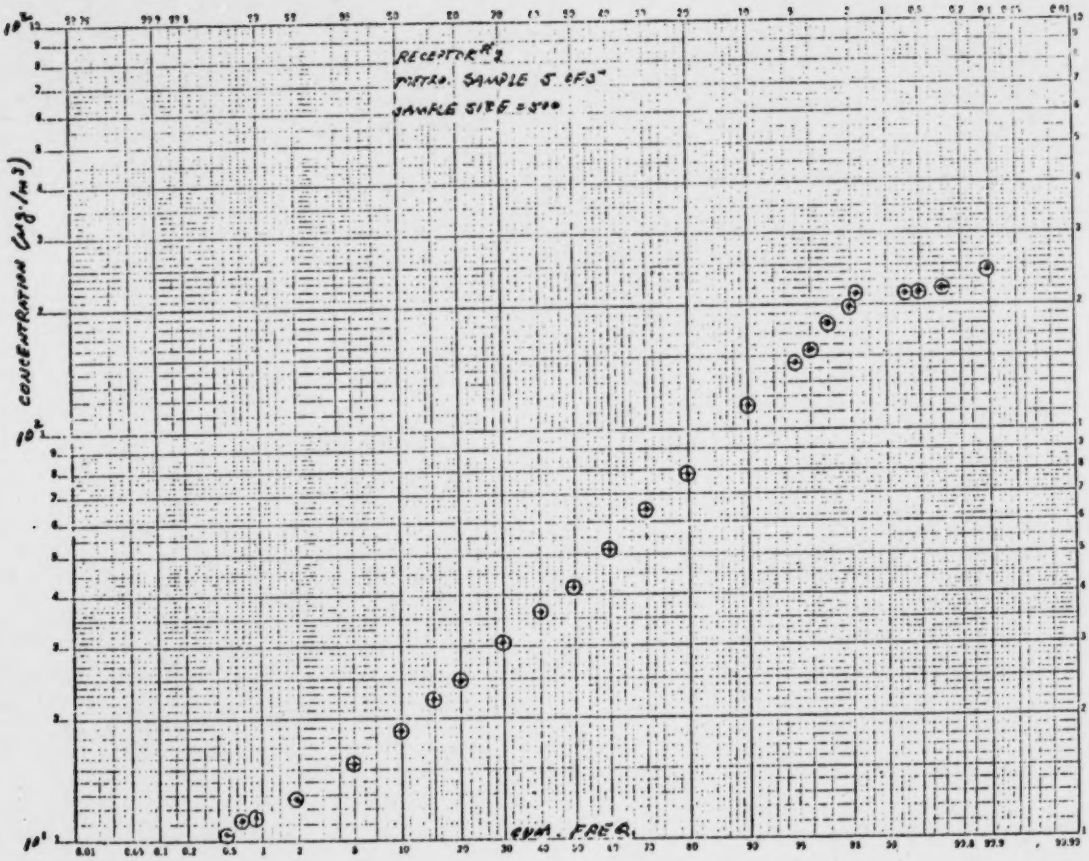

Figure 2. Cumulative Frequency Distribution of Total Concentration for Receptor 2.

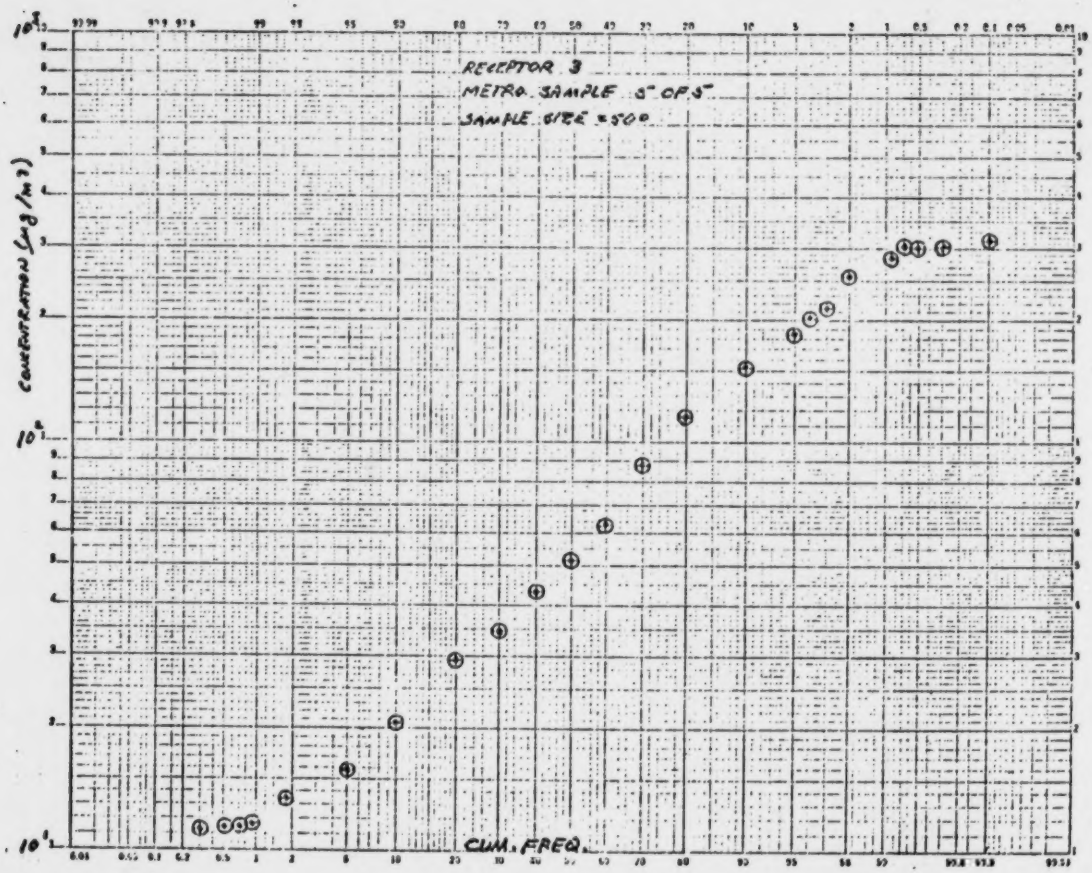

Figure 3. Cumulative Frequency Distribution of Total Concentration for Receptor 3.

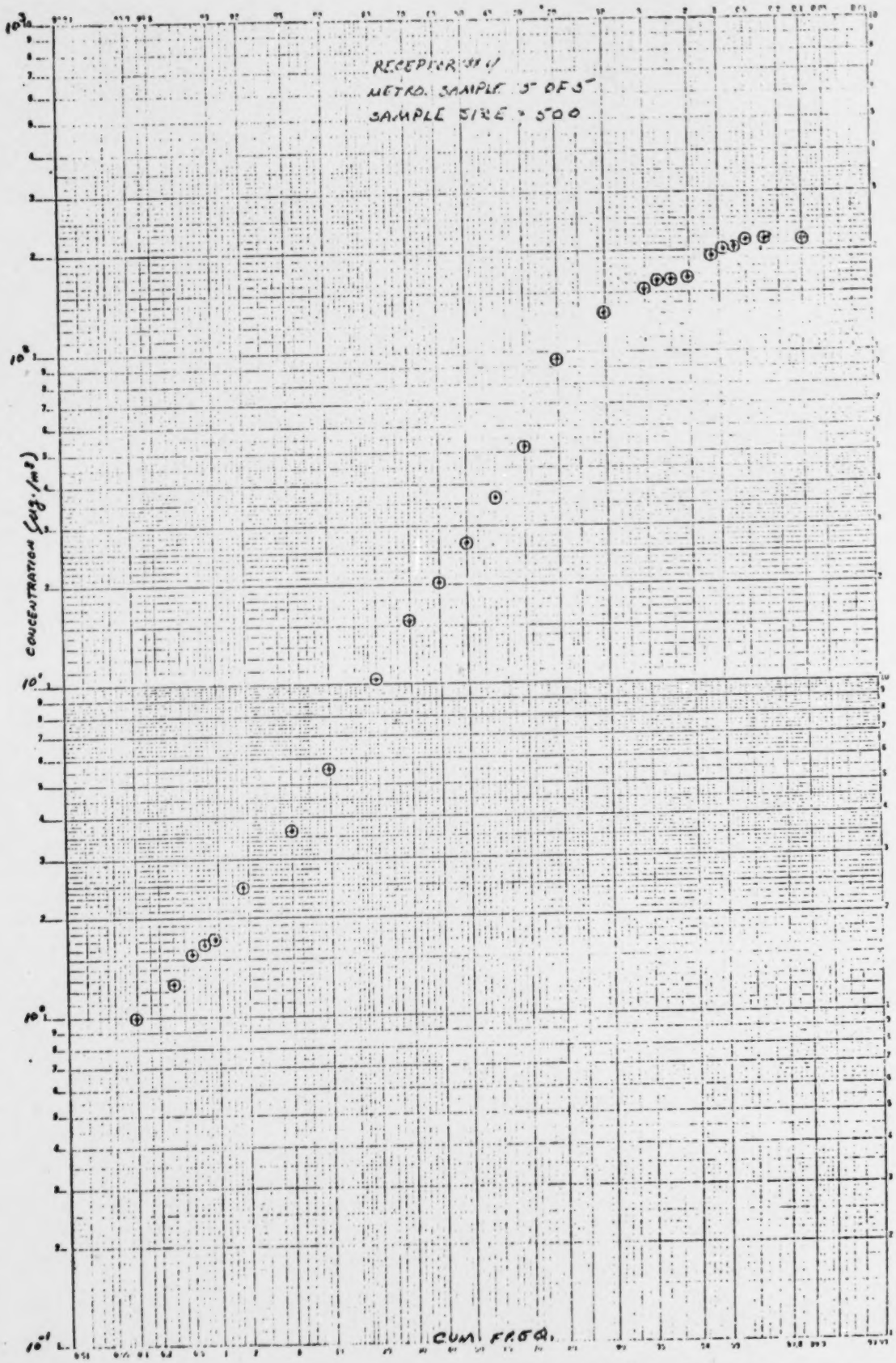

Figure 4. Cumulative Frequency Distribution of Total Concentration for Receptor 4.

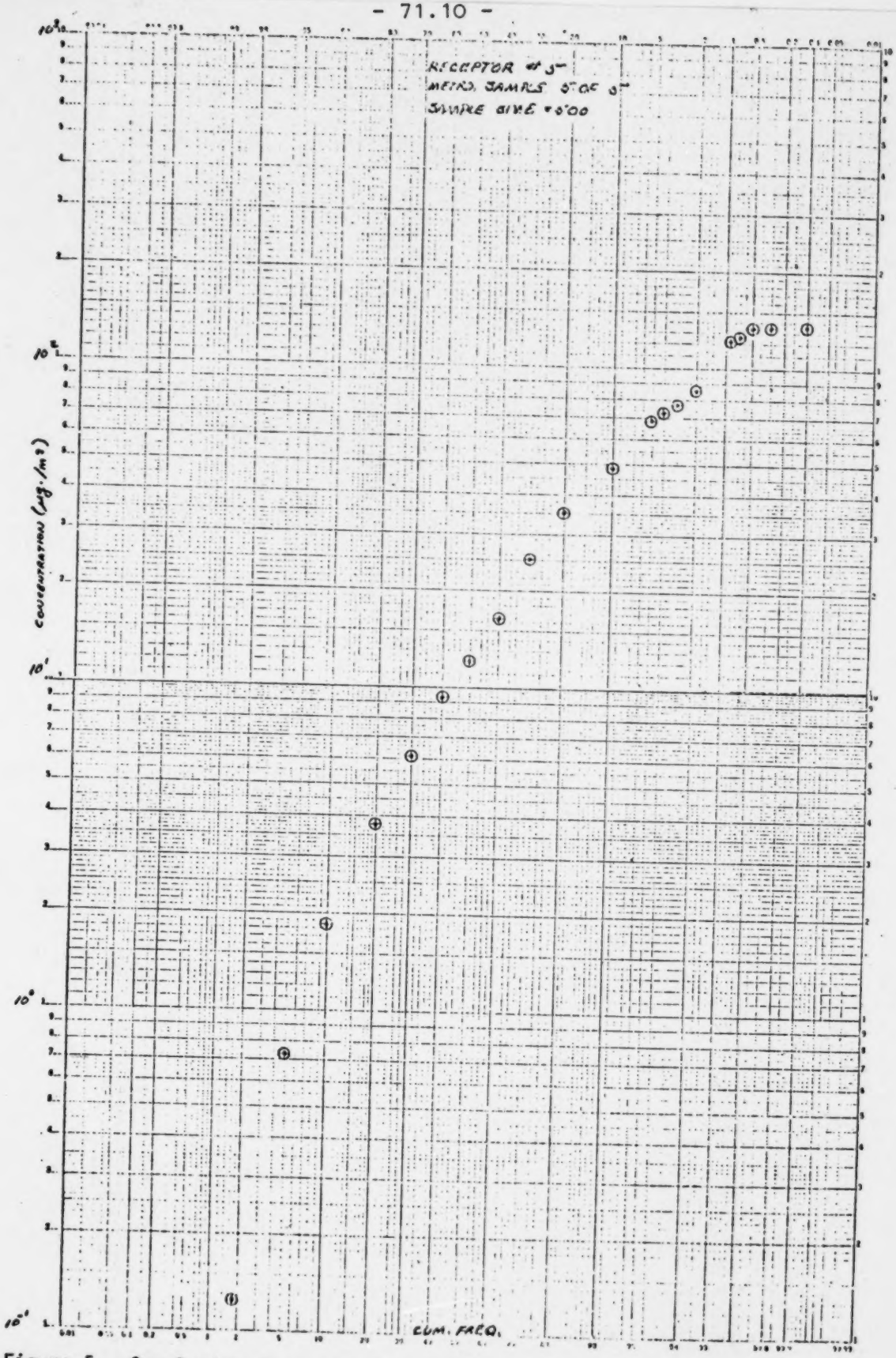

Figure 5. Cumulative Frequency Distribution of Total Concentration for Receptor 5.

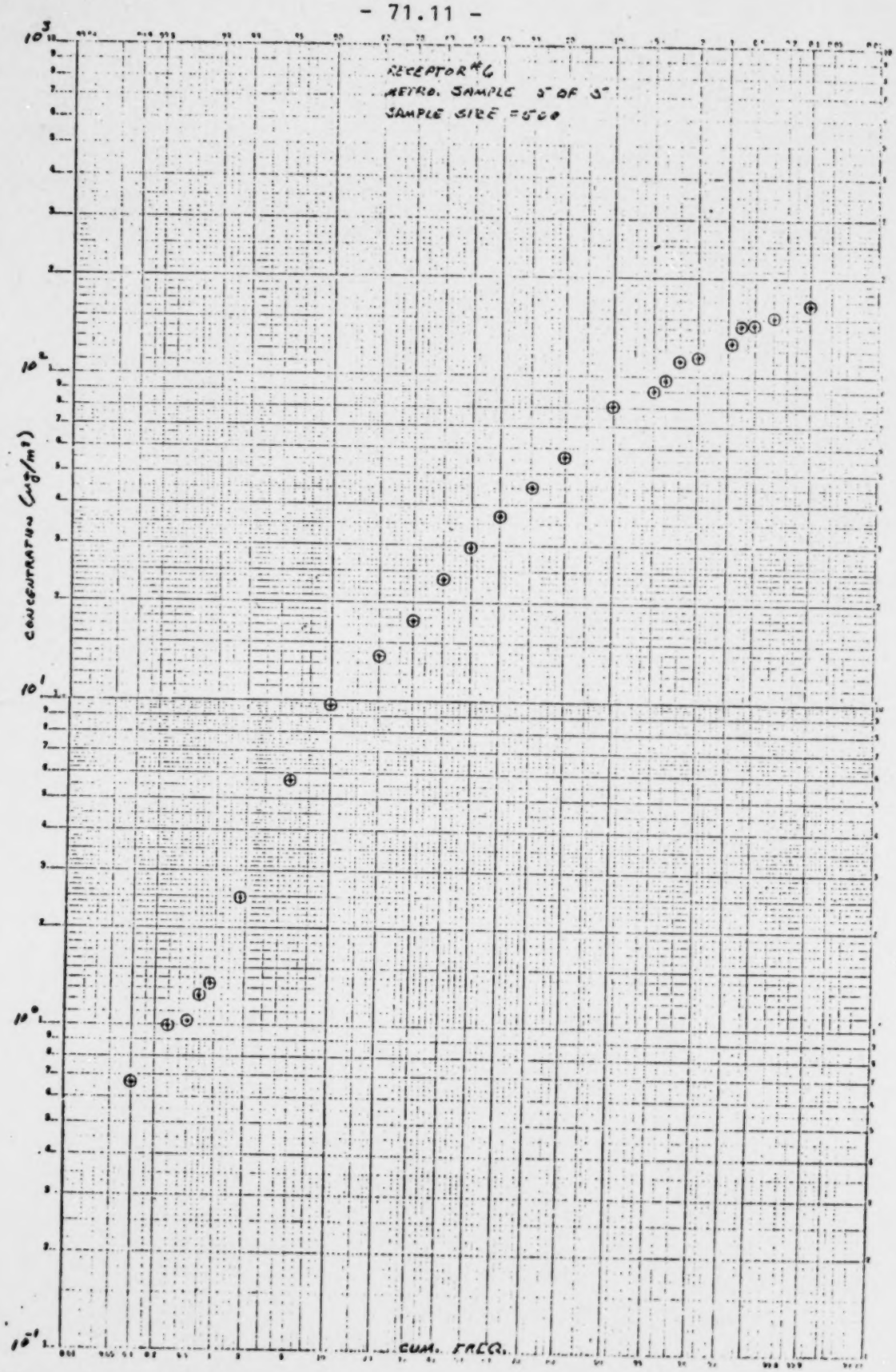

Figure 6. Cumulative Frequency Distribution of Total Concentration for Receptor 6.

Table 2. Peak Concentrations and Respective Meteorological Conditions for 6 Receptor Locations for Meteorological Sample # 5 of 500 Meteorological Conditions.

RECEPTOR NUMBER	FIVE HIGHEST CONCENTRATIONS ($\mu G/M^3$)	WIND DIRECTION (DEGREES)	WIND SPEED CLASS	STABILITY CLASS
1	257.9	62	1	6
	257.8	61	1	6
	256.7	58	1	6
	255.6	59	1	6
	253.2	60	1	6
2	244.5	344	1	5
	220.0	6	1	6
	216.8	8	1	6
	216.6	7	1	6
	213.4	4	1	6
3	329.0	83	1	6
	306.4	81	1	5
	303.5	87	1	5
	302.3	86	1	6
	286.9	78	1	6
4	218.2	91	1	6
	218.2	79	1	6
	215.5	78	1	6
	205.3	75	1	6
	201.2	81	1	5
5	135.7	117	1	6
	134.0	103	1	6
	133.5	100	1	6
	125.1	115	1	5
	122.1	104	1	6
6	166.6	260	1	5
	152.3	282	2	6
	144.4	267	2	6
	144.0	287	2	6
	128.8	226	1	6

REFERENCES

1. Irwin, J.S., 1976: A Frequency-Distribution Algorithm for Multiple-Source Short-Term Concentration. Documentation for Practical Demonstration of Urban Air Quality Simulation Models. Submitted to NATO/CCMS Panel on Modeling. March, 1976.

2. Turner, D. B., 1976: The Application of the CDM (Climatological Dispersion Model) to the NATO Common Data Base for Frankfurt. Documentation for Practical Demonstration of Urban Air Quality Simulation Models. Submitted to NATO/CCMS Panel on Modeling. August, 1976.

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THE APPLICATION OF THE CDM (CLIMATOLOGICAL DISPERSION MODEL) TO THE NATO COMMON DATA BASE FOR FRANKFURT PART II. WINTER AND SUMMER

by

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January 1977

*On Assignment from the National Oceanic and Atmospheric Administration, Department of Commerce

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INTRODUCTION

As part of the Practical Demonstration of Multiple Source Urban Air Quality Modeling sponsored by the Modeling Panel of the NATO/CCMS Air Pollution Pilot Study, Assessment Methodology and Modeling Working Group, two algorithms were documented (Turner, 1976a and Irwin, 1976a) and applied (Turner, 1976b and Irwin, 1976b) to the NATO Common Data Base for Frankfurt, Germany by the Environmental Applications Branch, Meteorology and Assessment Division, Environmental Sciences Research Laboratory, EPA. Both of these applications were made using an annual emission inventory and a joint frequency distribution of the three parameters: wind direction, wind speed, and stability class. At the time of these applications, information on the variability of emissions for the winter six-month period versus the summer six-month period was available. However, there was no separation of the

meteorological data for these two periods. In July 1976 a magnetic tape containing the synoptic observations for the modeling period (August 1, 1971 to July 31, 1972) became available. After some difficulty the tape was read. It was decided that computations would be first performed using CDM (36) (Turner, 1976a, 1976b) and assess the results before deciding on additional calculations with SCAM (Irwin, 1976a, 1976b). The method used to make these computations and the resulting concentrations are reported.

DATA BASE

METEOROLOGY

The surface observations of the meteorological conditions at Frankfurt-Main, Germany for the period from August 1, 1971 through July 31, 1972 were supplied on magnetic tape to the countries participating in the NATO/CCMS practical demonstration of Urban Air Quality Simulation Models in July, 1976. Using the techniques outlined by Turner (1964), a Pasquill-Gifford Stability class was determined for each of the 8 observations given for each day of the period. The period of 366 days was partitioned into two periods each of 183 days. From October 15, 1971 through April 15, 1972 was assumed to be a period when emission of SO_2 due to space heating (area sources) was important. The split period totaling 183 days from August 1, 1971 through October 14, 1971 and from April 16, 1972 through July 31, 1972 was assumed to be a period when no emission of SO_2 due to space heating occurred. A

joint-frequency distribution of three meteorological parameters was generated for the two 183-day periods. The distribution consisted of the 1296 possible combinations of 36 wind direction sectors, 6 wind speed classes, and 6 stability classes (Turner, 1976a).

EMISSIONS

From the supplied emission inventory of 681 point sources 1457 area sources (Jost, 1975), a separate emission inventory was assembled for each of the 183-day periods which reflected the seasonal variation in SO_2 emission rates. For the non-heating period it was assumed that no space heating occurred and that the point sources emitted SO_2 at the given summer emission rates. Only 522 point sources had non-zero summer emission rates, thus for the non-heating period, the emission data base consisted of 522 point sources and no area sources. For the heating period 674 point sources had non-zero winter emission rates. The area source emission rates were computed from the original data by multiplying the given emission per heating degree (Kg/Deg) by the total number of heating degrees (1560 Deg) and dividing by the duration of the heating period (183 x 24 = 4392 hr). The number of heating degrees (1560 Deg) was specified in a supplementary document to the original data base (Jost, 1976). Thus, for the heating period, the emission data base consisted of 674 point sources and 1457 area sources.

CALCULATIONS AND RESULTS

Calculations were made for the summer half of the year and the winter half of the year using CDM (36) for six receptor locations suggested by Jost (1976). The receptor coordinates and the average concentrations for the two periods are given in Table 1. The mean annual concentration resulting from these is also given and is the arithmetic average of the two periods since they each represent the same number of days (183).

The contributions from point and area sources for the winter period are shown in Table 2. As discussed in the Emissions section, all the summer emissions are from point sources.

Inspection of the concentration estimates for the six receptor locations reveals that the winter season concentrations and the annual concentrations can be approximated as multiples of the summer season concentrations. For instance, the winter point source contribution is approximately 2.0 times the corresponding summer point source contribution at each receptor location. The total winter season concentrations are approximately ten times the summer point source concentrations and the annual concentrations are approximately 5.7 times the summer point source contributions. If these relationships were to remain valid for any receptor location within the Frankfurt study area then the seasonal isopleth patterns for concentrations would be similar to the annual isopleth pattern. The isopleth values for the summer season would be approximately 0.17 times the annual isopleth values and the winter isopleth values would be approximately 1.75

times the annual isopleth values.

The concentrations made here for the two periods, summer and winter, are compared in Table 3 with the previous computations. Since the greatest change in mean annual concentration at the six receptors is only 8 percent, it was decided not to make similar new calculations for additional receptors in order to have sufficient coverage to draw isolines of mean annual concentration.

Also because of the small differences in concentration, it was decided not to apply SCAM to the separate summer and winter periods.

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TABLE 1. CONCENTRATIONS AT SIX RECEPTORS

Receptor Coordinates km		Sulfur Dioxide Concentrations $\mu g\ m^{-3}$		
East	North	Summer	Winter	Mean Annual
22.29	26.53	11.7	137.3	74.5
28.25	28.15	10.7	107.1	58.9
24.76	28.98	9.7	151.7	80.7
16.00	27.00	11.0	101.7	56.3
19.00	32.00	9.2	55.8	32.5
34.00	27.00	7.4	67.6	37.5

TABLE 2. WINTER CONCENTRATIONS FROM POINT AND AREA SOURCES

Receptor Coordinates km		Sulfur Dioxide Concentrations $\mu g\ m^{-3}$		
East	North	Point	Area	Total
22.29	26.53	22.2	115.1	137.3
28.25	28.15	18.5	88.6	107.1
24.76	28.98	22.7	129.0	151.7
16.00	27.00	18.5	83.2	101.7
19.00	32.00	17.7	38.1	55.8
34.00	27.00	14.0	53.7	67.6

TABLE 3. MEAN ANNUAL CONCENTRATIONS FROM SUMMER/WINTER CALCULATIONS COMPARED WITH PREVIOUS ESTIMATES

Receptor Coordinates km		Concentrations $\mu g\ m^{-3}$		Ratio of Summer/Winter to Previous Estimates
East	North	Previous	Summer/ Winter	
22.29	26.53	71.1	74.5	1.05
28.25	28.15	59.7	58.9	0.99
24.76	28.98	76.3	80.7	1.06
16.00	27.00	53.2	56.3	1.06
19.00	32.00	30.0	32.5	1.08
34.00	27.00	37.1	37.5	1.01

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Gifford; USA

NATO/CCMS PANEL ON MODELING

Documentation for Practical Demonstration
of Urban Air Quality Simulation Models

ANNUAL AVERAGE SO_2 CONCENTRATION ESTIMATES FOR SIX FRANKFURT STATIONS, BASED ON NATO/CCMS STANDARD DATA BASE FOR THE PRACTICAL DEMONSTRATION

by

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Annual Average SO_2 Concentration Estimates for Six Frankford Stations, Based on NATO/CCM Standard Data Base for the Practical Demonstration

The simple ATDL urban diffusion model has been used to estimate annual average SO_2 for the 6 stations identified in Ref. (2), with the area and point source data given in Ref. (1). A description of this model is contained in Ref. (3). Since other participants in the "practical demonstration" will be evaluating various more complex models, also based on Gaussian plume formations, it seemed that the best contrast with our model would be provided by applying it in its more elementary form. Accordingly I have used the equation

$$X = c\ Q/\bar{u} \qquad (1)$$

where X is the average annual SO_2 concentration, Q is the area-source strength in the region around each verification station, and $\bar{u}$ is the mean annual wind speed in the Frankfort region.

The value of the quantity c varies primarily with atmospheric stability statistics, as described in many references. In the case of reactive pollutant like SO_2, c also depends on removal and chemical reaction effects. For the present exercise, c was evaluated by a direct comparison with the Frankfort air quality data given in Ref. (4).

Based on many previous comparisons for various cities, see for example Refs. (3) and (6), a 2x2 km area source was chosen, centered at the grid intersection nearest each of the 6 verification points. Area source contributions in these 2x2 km regions were determined from

the data of Ref. (1). In addition the contributions from all point sources in the same 6 areas, whose geometric height is $\geq$40 m, was determined. The result is as follows:

Station No.	Receptor Point Coordinates	Annual Average 2x2 km Area Source Strengths, kg hr^{-1}	Annual Average Pt. Source Strength, h $\geq$ 40 m, in 2x2 km Areas, kg hr^{-1}
1	2229,2653	530	19
2	2825,2815	1154	18
3	2476,2896	1007	32
4	1600,2700	254	7
5	1900,3200	74	8
6	3400,2700	309	31

The figure 40 m is arbitrary. However the influence on SO_2 concentration at the 6 points of all higher SO_2 point sources in the 2x2 km areas, plus all other point sources whose strength is $\geq$5 kg hr^{-1}, was determined to be negligible by a separate point source calculation.

Equation (1) was then evaluated as follows. The area source strength for each area was determined by combining the above area and point sources. That is, no separate, detailed point-source calculation was made. The average transport wind speed in the Frankfort region is estimated, based on meteorological data given in Ref. (4), to be $\bar{u} \approx 2$ m sec^{-1}.

Estimates of observed annual average SO_2 concentrations for the given 6 stations were interpolated from the observations presented in Ref. (4), Maps 15 and 16. From these, with the source data and $\bar{u} = 2$ m sec^{-1}, c of Eq. (1) is readily found. The average value for the period April '71 - March '72 is c = 9.2. For the period April '72 - March '73, c = 7.4. (It is interesting that an approximately 20% reduction in SO_2 levels seems to have been achieved over that period.)

The actual verification period of this test is not given in Refs. (1) and (2). Assuming, however, that it coincides with the period of the meteorological data base mentioned in Ref. (1), i.e. Aug. 1971 to July 1972, I'm inclined to average the two c values. Thus a direct evaluation of the formula would be based on

$$X = 8.3\ Q/\bar{u} \qquad (2)$$

However it is apparent from the information given in Ref. (4) that account should be taken of a fairly strong SO_2 background of these sites, see for instance Map 26. As an improvement over Eq. (2) I have accordingly used

$$X = 3.0\ Q/\bar{u} + .04 \qquad (3)$$

which accounts for a background SO_2 value of .04 mg m^{-3}. Thus the final estimates are:

Station Number	Estimated SO_2, mg m^{-3}
1	.10
2	.16
3	.15
4	.07
5	.05
6	.07

Discussion

Some points should be noted.
1) The influence of station #5 on this result is very strong. Since the source strength in Station 5 is quite a lot lower compared to the concentration level, than for the other stations, I'd be inclined as a practical matter to leave it out of the c-computation. However I have no specific reason for doing this and suggest it only as a practical technique, not used for this test. In other words my estimates indicate that Station #5 is an odd-ball for some reason.

2) I calibrated c in the ATDL model by using available SO_2 air quality data for the Frankfort region. This gave me a c-value, 8.3, that is near the lower end of the range we have experienced elsewhere, see e.g. Ref. (6). Knowing nothing else, we would normally have expected $c \simeq 50$, based on the average of our experience in other cities.

But the value of c for SO_2 is strongly affected, as pointed out above, by many factors such as SO_2 removal, conversion, deposition, and so on. All these act in the same direction, to reduce c. None of these factors is however yet considered in any (non-reactive) Gaussian-plume type of urban model as far as I know.

The only obvious, remaining adjustable parameter in these models is the source height. Such an adjustment was, for instance, made by Herrmann (Ref. 5).

On the contrary, we have always believed that the lower c-values we find for SO_2 (compared for instance with particles) is mainly due to removal effects. The reason is that we always have found a c-value for particles on the order of its theoretical value, i.e.

$$c = (2/\pi)^{1/2}\, x^{1-b}\, [a(1-b)]^{-1} \simeq x/\sigma_z \qquad (4)$$

where

$$\sigma_z = a\, x^b\ . \qquad (5)$$

In the same locations, however, c for SO_2 is as a rule smaller by a factor averaging 4.5. We believe SO_2 conversion, and removal (such as by interaction with vegetation) are the main cause of this, although (see Ref. 6) the generally higher elevation of SO_2 sources than particulate sources could well be a factor.

3) Our SO_2 estimates give a correlation of about .8 with the interpolated X-values we used. Since it might be objected that we are "loading the dice" by using this procedure (although it is our normal, published practice), please note that the correlation coefficient between X-values and the above-given Q-values will be just as high. Thus, the source-strength pattern, in such an application of our model, gives the pattern of the concentration estimates. The level of these estimates depends on the c-value; but the pattern, and hence the correlation, do not.

4) Based on the above, I expect that our SO_2 estimates will correlate well, in the range r = .6 to .8 or so, with the actual verification SO_2 data values for the 6 stations. I expect that other, more complex Gaussian models will also perform in this range. I would guess that the correlation values for the other models would not differ significantly from that for the ATDL-values, but will be looking for the ATDL model to be on the high end of the list. I consider it much more likely, based on many previous such comparisons, that it would be near the top than near the bottom. We will see, of course, when all the results are in.

References

(1) Standard data based for practical demonstration. Memo D. Jost to Modeling Panel, NATO/CCMS, dated 12 January 1975.

(2) Supplement to above, D. Jost, dated March 1976.

(3) NATO/CCMS, Rep. No. 30, "Air Pollution, Proc. of 4th Meeting of the Expert Panel," May 1973, Chapter XVI.

(4) NATO/CCMS, Rep. No. 6, "Air Pollution, Appendix C.", June 1974.

(5) NATO/CCMS, Rep. No. 42, "Air Pollution, Proc. 6th Int. Tech. Meeting," 1975, pp. 61-74.

(6) F. Gifford and S. Hanna, 1973, Atmos. Envir., 7, 131-136.

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Braig (ATDL, CDM);
Fed. Rep. of Germany (2x)

Subject: NATO/CCMS Air Pollution Pilot Study
here: Practical Demonstration of an Urban Air Quality Simulation Model (CDM)

A. Braig Battelle Institute Frankfurt, Germany

1. Zusammenfassung

Das Vielquellen-Diffusionsmodell CDM wurde zur Berechnung von Jahresmittelwerten und zur Berechnung der Summenhäufigkeit der SO_2-Konzentration an ausgewählten Punkten in einem vorgegebenen Untersuchungsgebiet angewendet. Die Emissions- und meteorologischen Daten des Untersuchungsgebietes standen als "Standard Data Base" zur Verfügung. Nachfolgend werden die Anpassung der "Standard Data Base" für die Rechnung mit dem CDM-Modell und die mit dem Modell erzielten Resultate beschrieben.

2. Durchführung der Modellrechnung

2.1. Der Input meteorologischer Daten

Der "Standard Data Base" wurde die dreidimensionale Häufigkeitsverteilung der meteorologischen Parameter Windrichtung, Windgeschwindigkeit und Stabilitätsklasse für Quellhöhen $H < 100$ m mit der Klug'schen Klasseneinteilung entnommen.

Die Häufigkeitswerte für umlaufende Winde wurden jeweils den entsprechenden Häufigkeitswerten der einzelnen Sektoren gleichmäßig zugeschlagen.

Der Häufigkeitswert der Windstille pro Stabilitätsklasse wurde auf alle Sektoren mit FF = 0,1 gleichmäßig aufgeteilt.

Die Häufigkeitsverteilung innerhalb einer Stabilitätsklasse wurde danach so normiert, daß sich eine Gesamthäufigkeit von 100 Prozent über alle Stabilitätsklassen ergibt.

Die ursprünglich nach Knoten aufgeschlüsselten Windgeschwindigkeitsbeobachtungen wurden in sechs Klassen zusammengefaßt. Es wurde folgende Klasseneinteilung der Windgeschwindigkeiten gewählt.

Klassenbreite (kn)	1-2	3-5	6-8	8-12	13-17	18-30
Klassenmitte (m)	1	2,1	3,6	5,3	7,5	10,2

Als Streuungsparameter für $\sigma_z = ax^b$ wurden die von Prof. Klug vorgeschlagenen Werte nach Pasquill (neu) verwendet.

Stabilitätsklasse	Streuungsparameter	
I	0.11727	0.67
II	0.14856	0.73
III_1	0.19943	0.80
III_2	0.22294	0.80
IV	0.22547	0.85
V	0.27934	0.90

Für eine Berechnung des Windprofils $u(z) = u_o(z/z_o)^m$ wurden die folgenden Werte für den Exponenten m eingesetzt:

Stabilitätsklasse	I	II	III_1	III_2	IV	V
m	0,4	0,4	0,28	0,22	0,1	0,1

Jeder Stabilitätsklasse wurde eine Mischungsschichthöhe zugeordnet:

Stabilitätsklasse	Mischungsschichthöhe (m)
I	0
II	0
III_1	1200
III_2	1200
IV	1500
V	1800

2.2. Emissionskataster

2.2.1. Hausbrand (Flächenquellen)

Die Daten des Emissionskatasters für Hausbrandemission lagen vor für Flächenquadrate der Größe 500 x 500 m. Das Kataster hat eine Ausdehnung in östlicher Richtung von 38 km und in nördlicher Richtung von 26 km. Der südwestliche Eckpunkt hat die Koordinaten: RW 9/00, HW 18/00.

Für jedes Flächenelement von 500 x 500 m enthält das Emissionskataster folgende Angaben

- mittlere Bebauungshöhe
- maximale SO_2-Emission des Flächenelements bei einer Temperatur von -12°C.

Die Emissionsraten wurden entsprechend einer mittleren Anzahl von 1560 Heizstunden auf durchschnittliche Jahresemissionsraten umgerechnet.

Da es rechenzeitmäßig undurchführbar war, jedes Flächenelement der Größe 500 x 500 m zu berücksichtigen, wurden vier Flächenquadrate zu einem Flächenquadrat von 1 x 1 km zusammengefaßt, falls die Eckpunkte dieses Quadrates mit den Gitterpunkten eines Netzes der Maschenweite 1 km zusammenfallen, und die Streuung der Quellstärken kleiner als der arithmetische Mittelwert der einzelnen Quellstärken ist.

Die Quellhöhe eines Flächenquadrates von 1 x 1 km wurde als mit der Quellstärke gewichteter arithmetischer Mittelwert der Quellhöhen der Flächenquadrate von 500 x 500 m berechnet.

2.2.2. Einzelemittenden

Das Emissionskataster der "Standard Data Base" enthält 681 individuell erfaßte Quellen (Punktquellen). Diese Quellen wurden in 2 Klassen eingeteilt. Der ersten Klasse wurden alle Quellen mit einer Quellstärke großer 5 kg/h zugeordnet. Ebenfalls diejenigen Quellen mit einer Quellstärke kleiner 5 kg/h und mit einer physikalischen Schornsteinhöhe größer

als 40 m. Die restlichen Quellen wurden der Klasse 2 zugeordnet, insbesondere all diejenigen Quellen mit einer Quellstärke kleiner 1 kg/h. Die Emittenden der Klasse 2 wurden dem Hausbrand zugeordnet und gleichmäßig auf die Hausbrandemissionen des betreffenden Flächenelementes verteilt. Auf die Klasse 1 entfallen 188 Quellen.

2.3. Struktur des CDM-Modells

Die Struktur des CDM-Modells ist in einem früheren Dokument ausführlich dargelegt. An dieser Stelle wird daher nicht weiter auf sie eingegangen.

3. Ergebnisse

Jahresmittelwerte der SO_2-Konzentration wurden berechnet für ein Netz von Aufpunkten mit einer Entfernung von jeweils 2 km. Der südwestliche Eckpunkt des Netzes hat die Koordinaten (RW/HW) 1400/2300. Die Seitenlängen des Netzes sind 20 bzw. 12 km lang. An den einzelnen Aufpunkten wurden die Emissionen aller Quellen berücksichtigt.

Das nachfolgehde Bild enthält eine Isoliniendarstellung der Jahresmittelwerte der SO_2-Konzentrationen. Die Einheit des Mittelwertes ist $\mu g/m^3$.

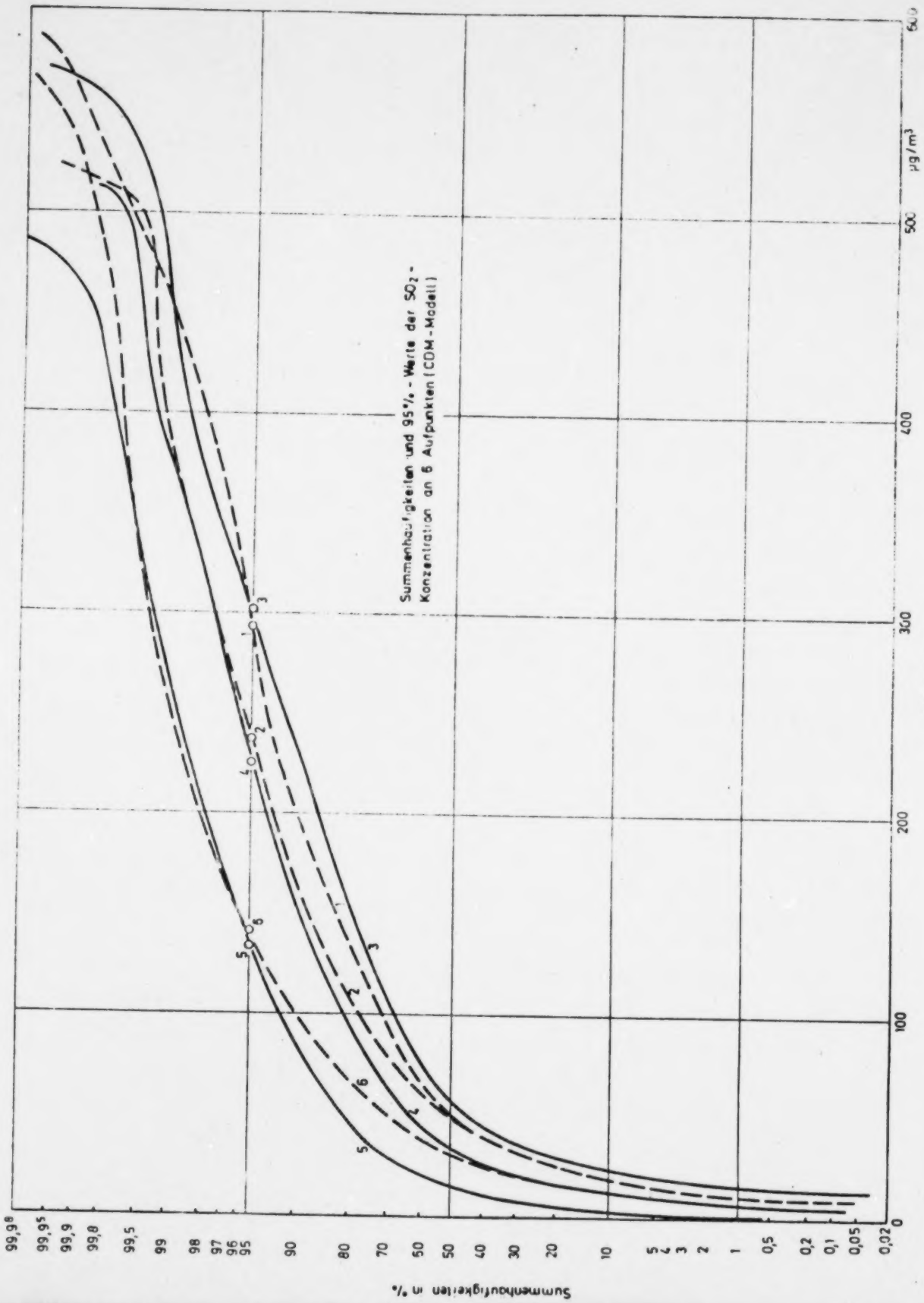
Zusätzlich wurde der Jahresmittelwert und der 95 %-Wert der Summenhäufigkeit an sechs weiteren Aufpunkten berechnet. Die nachstehende Tabelle enthält die Koordinaten dieser Punkte und die berechneten Werte.

Nr.	Koordinaten RW	HW	Mittelwert ($\mu g/m^3$)	95 %-Wert ($\mu g/m^3$)
1	2229	2653	100.7	293.1
2	2825	2815	87.3	231.7
3	2476	2898	112.4	304.4
4	1600	2700	76.6	222.4
5	1900	3200	48.2	133.4
6	3400	2700	53.5	143.7

Das abschließende Bild zeigt die Summenhäufigkeiten der Konzentrationen an den sechs zusätzlichen Aufpunkten und die 95 %-Werte.

4. Rechenzeit

Zur Berechnung der SO_2-Konzentrationen an 83 Aufpunkten wurde auf der Rechenanlage Burroughs B6700 3 h 12 min Rechenzeit benötigt.


Summenhaufigkeiten und 95%-Werte der SO_2-Konzentration an 6 Aufpunkten (COM-Modell)
Summenhaufigkeiten in %
99,98
99,95
99,9
99,8
99,5
99
98
97
96
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
0,5
0,2
0,1
0,05
0,02
0
100
200
300
400
500
600
µg/m³
1
2
3
4
5
6

Subject: NATO/CCMS Air Pollution Pilot Study
here: Practical Demonstration of an Urban Air Quality Simulation Model (Revised ATDL-Model)

1. Zusammenfassung

Das modifizierte Vielquellendiffusionsmodell ATDL wurde zur Berechnung von Jahresmittelwerten und zur Berechnung des 95 %-Wertes an ausgewählten Punkten in einem vorgegebenen Untersuchungsgebiet angewendet.

Die Emissions- und meteorologischen Daten des Untersuchungsgebietes standen als "Standard Data Base" für die Rechnung mit dem ATDL-Modell zur Verfügung.

Nachfolgend werden die Anpassung des "Standard Data Base" für die Rechnung mit dem CDM-Modell und die mit dem Modell erzielten Resultate beschrieben.

2. Durchführung der Modellrechnung

2.1. Der Input meteorologischer Daten

Die für die Rechnung mit dem CDM-Modell erstellte auf einer 36-teiligen Windrose basierenden Häufigkeitsverteilung wurde auf eine Häufigkeitsverteilung mit 16 Sektoren umgerechnet. Das ATDL-Modell gestattet lediglich die Eingabe einer derartigen Häufigkeitsverteilung.

Die Klasseneinteilung der Windgeschwindigkeiten ist dieselbe wie bei der Anwendung des CDM-Modells.

Als Streuungsparameter für $\sigma_z = ax^b$ wurden ebenfalls die Werte von Pasquill (neu) verwendet. Für dem Exponenten m zur Berechnung des Windprofils wurden ebenfalls dieselben Werte wie im CDM-Modell benutzt. Das ATDL-Modell berücksichtigt keine Mischungsschichthöhen.

2.2. Emissionskataster

2.2.1. Hausbrand (Flächenquellen)

Da Immissionswerte nur für ein bestimmtes Teilgebiet berechnet wurden (s. Pkt. 3), wurden aus dem Emissionskataster der "Standard Data Base" nur diejenigen Flächenquellen berücksichtigt, die innerhalb eines Rechteckes mit dem südwestlichen Eckpunkt (RW/HW) 900/1700, einer Länge von 32 km und einer Breite von 24 km liegen.

Alle Flächenquadrate von 500 x 500 m wurden zu Flächenquadraten von jeweils 1 x 1 km zusammengefaßt. Die Emissionraten wurden analog wie im CDM auf mittlere Jahresemissionsraten umgerechnet. Als Quellhöhe für ein Flächenelement von 1 x 1 km wurde diesem jeweils der arithmetische Mittelwert der Höhen der Flächenquadrate von 500 x 500 m zugeordnet.

2.2.2. Einzelemittenden

Es wurden ebenfalls nur die bei der Durchrechnung des CDM Modells ausgewiesenen Quellen der Klasse 1 (insgesamt 188) als Punktquellen berücksichtigt. Die Quellkoordinaten der Punktquellen wurden entsprechend den Modellvoraussetzungen auf den Mittelpunkt desjenigen Flächenquadrates umgerechnet, innerhalb dessen die Quelle liegt. Die effektive Quellhöhe der Punktquellen wurden für jede Stabilitätsklasse gesondert einer "Quellhöhenklasse" zugeordnet. Als Klassenbreite wurden dh = 30 m gewählt.

2.3. Struktur des ATDL-Modells

Die Struktur des ATDL-Modells ist in einem früheren Dokument ausführlich dargelegt. An dieser Stelle wird daher nicht weiter auf sie eingegangen.

3. Ergebnisse

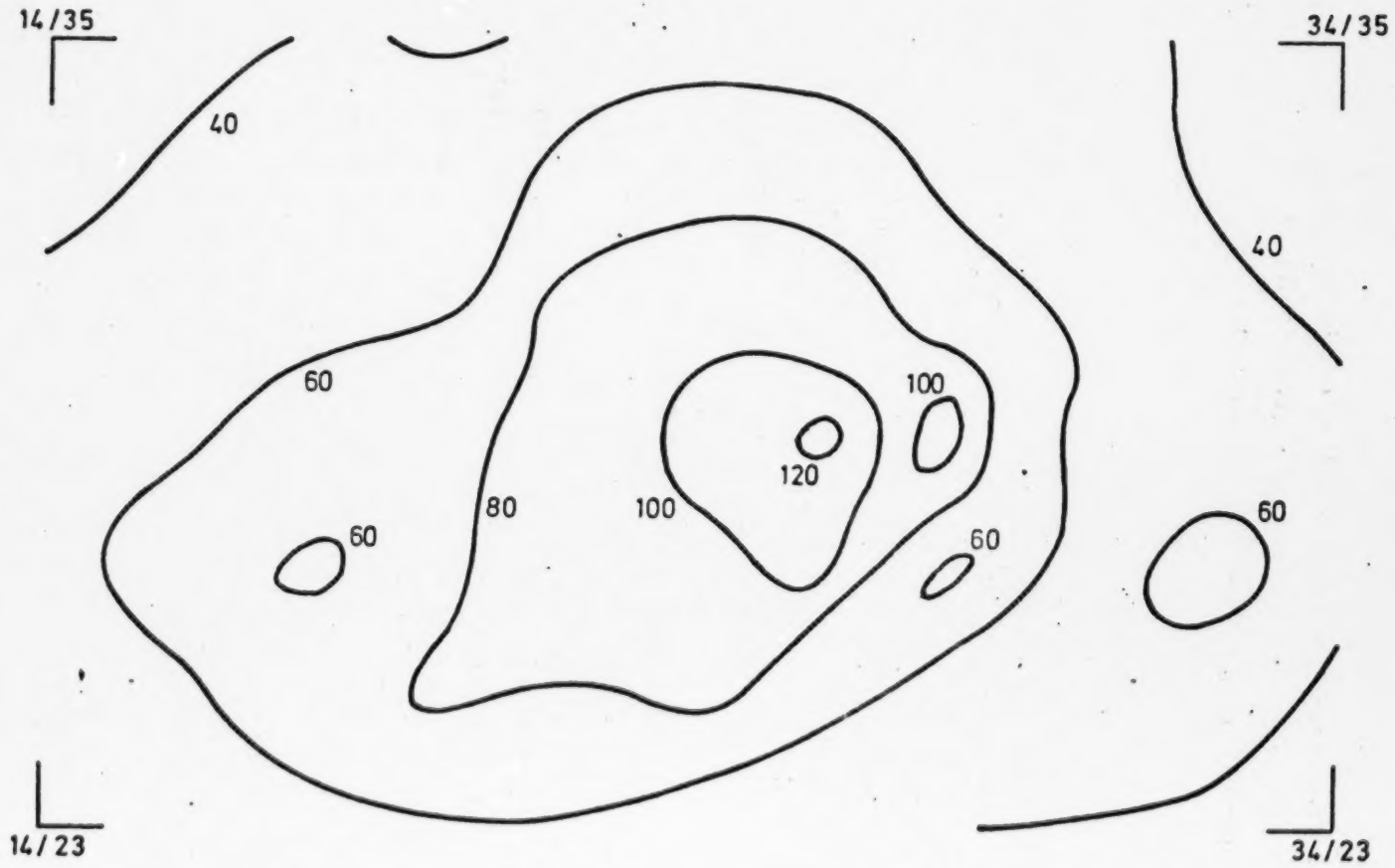
Jahresmittelwerte der SO_2-Konzentration wurden berechnet für ein Netz von Aufpunkten mit einer Entfernung von jeweils 1 km. Der südwestliche Eckpunkt des Netzes hat die Koordinaten (RW/HW) 1450/2350. Die Seitenlängen des Netzes sind 19 bzw. 11 km lang. Die Aufpunkte befinden sich jeweils im Mittelpunkt eines Flächenquadrates. Das nachfolgende Bild enthält eine Isoliniendarstellung der Jahresmittelwerte der SO_2-Konzentration. Zusätzlich wurde der Jahresmittelwert und der 95 %-Wert der Summenhäufigkeit an sechs weiteren Aufpunkten jeweils aus den Werten der benachbarten vier Aufpunkte berechnet. Die nachstehende Tabelle enthält die Koordinaten dieser Punkte und die berechneten Werte.

Die vorliegende Version des ATDL-Modells ermöglicht nicht die Ausgabe derartiger Werte, die eine graphische Darstellung der Summenhäufigkeiten der Konzentrationen ermöglichen.

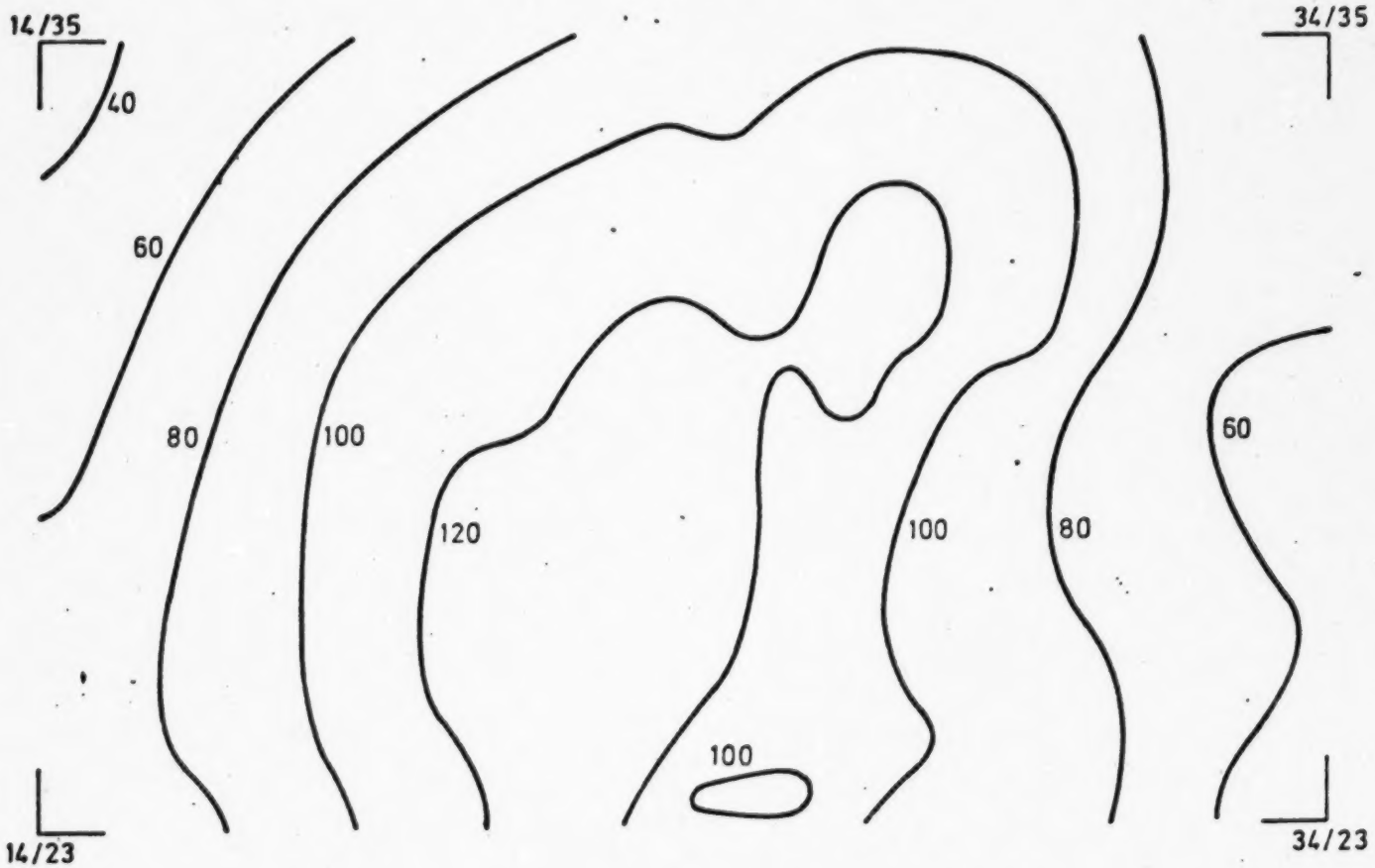
Nr.	Koordinaten RW	Koordinaten HW	Mittelwert ($\mu g/m^3$)	95 %-Wert ($\mu g/m^3$)
1	2229	2653	130.9	572.9
2	2825	2815	94.9	294.2
3	2476	2898	121.1	395.4
4	1600	2700	78.9	252.5
5	1900	3200	89.8	311.6
6	3400	2700	52.8	162.8

4. Rechenzeit

Zur Berechnung der SO_2-Konzentrationen an 240 Aufpunkten wurde auf der Rechenanlage Burroughs B6700 53 min benötigt.



Isolinien der Jahresmittelwert der SO_2 - Konzentration ($\mu g/m^3$)
berechnet mit CDM



Isolinien der Jahresmittelwerte der SO_2 - Konzentration ($\mu g/m^3$)
berechnet mit ATDL

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Stern, Gutsche, Timm;
Fed. Rep. of Germany (2x)

NATO /CCMS PILOT STUDY AIR POLLUTION
Practical Demonstration of Urban Air Quality Simulation Models

Calculation of the ambient air quality situation
using the NATO /CCMS common data base for the 'Test-City'

by

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Berlin 1977

SUMMARY

Fortak's long-term multiple-source urban diffusion model, which is described in this report, has been applied to the NATO /CCMS Standard Data Base for the Test-City Frankfurt. Isopleths of annual mean SO_2-ground level concentrations have been mapped for the whole region. Annual mean concentrations and cumulative frequency distributions are also given for six specified receptor sites. First incomplete results of a sensitivity analysis are presented.

1. Introduction

The multiple-source urban diffusion model described in chapter 2 has been applied to the NATO /CCMS common data base, published in Techn. Doc. M. P. 2/1975 2.4.G. "Standard Data Base".

First calculations on the basis of these data have shown that these data were not suitable to meet all possibilities of the dispersion model. Therefore, the magnetic tape with the original meteorological data has been used for the model calculations.

As a result annual mean values and cumulative frequency distributions for selected receptor sites are presented within this study as well as isopleths for the annual mean values of the SO_2-ground-level concentrations.

2. Brief description of the dispersion model

A brief description of Fortak's multiple source urban diffusion model is given in (1), a detailed model- and program-description can be found in (2). Some examples of model applications are presented in (3) to (5).
At this place, only some essential elements of the model structure shall be repeated, followed by the results of the application of this model to the common data basis for the Test-City.

FORTAK's model, which has been applied in this study to the NATO /CCMS common data basis, represents a climatological GAUSSian plume model which allows for calculating annual averages and cumulative frequency distribu-

tions of ground-level concentrations as an immission climatological basis for planning activities.

According to the various questions arising in planning problems, there exist two different versions of this model

- a source-oriented version which is being used to calculate complete immission-concentration-fields for regional planning of ambient air quality;
- a receptor-oriented version which allows concentration calculations for an optional number of selected receptor-sites with arbitrary positions.

The second version saves computation time and has been developed

- for special requirements in German licensing procedures;
- for optimization of measurement planning;
- for representivity investigations of receptor sites,
- for sensitivity analyses of the model;
- for direct model validation by choosing the position of the calculation point as identical with that of the measuring site.

Both versions have been applied to the NATO /CCMS common data basis for the 'Test-City'.

Sources

All sources with an SO_2-emission of more than 1 kg SO_2/h are treated as individual point sources; space heating and sources with an SO_2-emission less than 1 kg/h are comprised to area sources.

The basic equation for point sources is given by

$$\chi = \frac{Q}{\bar{u}} \exp(-\gamma\tau) \frac{\exp\left[-\frac{y^2}{2\sigma_y^2}\right]}{\sqrt{2\pi}\,\sigma_y} \quad S$$

The exponential factor $\exp(-\gamma\tau)$ is accounting for transformation and loss processes during the travel time τ. Within this study the effect of these transformation and loss processes has been neglected.

The functional S takes the form

$$(\text{a})\ S = \frac{1}{\sqrt{2\pi}\,\sigma_z} \left\{ \exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right] \right\}$$

for total reflection of pollutants at the earth's surface and when there is no inversion;

$$(\text{b})\ S = \frac{1}{2H_I} \left\{ \Theta_3\left(\frac{z-H}{2H_I}; \frac{\sigma_z^2}{2H_I^2}\right) + \Theta_3\left(\frac{z+H}{2H_I}; \frac{\sigma_z^2}{2H_I^2}\right) \right\}$$

with $$\Theta_3(V; W) = \frac{1}{\sqrt{\pi W}} \sum_{n=-\infty}^{+\infty} \exp\left[-\frac{(V+n)^2}{W}\right]$$

for total reflection at the earth's surface as well as at an inversion in height H_I.

Because no data about the inversion height H_I were available in the common data basis, functional form (a) has been used within this study.

To determine the plume rise for singular emittents STÜMKE's formula (STÜMKE (6))

$$\Delta h = \frac{1}{\bar{u}_1} \left\{ 1.5\, v_s\, d_s + 65\, d_s^{3/2} \left(\frac{\Delta T}{T_s} \right)^{1/4} \right\}$$

has been used with

$$\bar{u}_1 = \frac{1}{\Delta h} \int_h^{h+\Delta h} u(z)\, dz$$

where h represents the physical stack height.

Area sources of 500 m x 500 m (or 1000 m x 1000 m) are simulated using 100 individual point sources uniformly distributed over the gridsquare The source strength of each of these point sources is 1/100 of the area source strength, and the emission height corresponds to the mean conditions within the grid square. The contribution of these sources to the concentration field is calculated with the same basic equations as described above.

The plume rise of these area-sources is determined by the following stability-dependent rule-of-thumb:

TURNER stability class	2	3	4	5	6
$\bar{u}_1 \cdot \Delta h$	25	21	19	17	11 m^2/s

Meteorology

For the main applications of this model a three-dimensional frequency distribution of wind direction, wind speed, and stability classes is used.

For wind direction a 36-classes-wind rose of 10^0-sectors is used, for model calculations each 10^0-sector is subdivided into 5 2^0-sectors under the assumption of uniform distribution within the corresponding 10^0-sector. This procedure ensures that each plume, even a very small one, is considered by the model calculation.

Due to the specific climatological situation of the Test-City Frankfurt a wind speed classification of the following 6 classes seems to be sufficient. According to the basic assumptions, inherent in GAUSSian plume models, calms and weak-wind situations with wind speeds less than 1.5 m/s are excluded. This aspect has to be considered when model validations are being performed (see for example (5)).

Wind speed class	wind speed intervall	representative class-speed (m/s)
1	≤ 3	0.9 (class 1 being excluded)
2	4	1.7
3	5,6	2.4
4	7 - 9	3.6
5	10 - 13	5.2
6	≥ 14	7.1

For the vertical wind profile a power law is assumed

$$u(z) = u(z_0) \left(\frac{z}{z_0}\right)^m$$

with stability-dependent exponent m.

TURNER stability class	2	3	4	5	6
m	0.111	0.208	0.288	0.396	0.419

For stability classification TURNER's scheme (7) has been used. The corresponding diffusion parameters are derived from power laws

$$\sigma_y = F x^f \; ; \quad \sigma_z = G x^g$$

the stability-class-dependent parameters F, f, G, g

- after McELROY and POOLER (8) for effective stack heights less than 40 m,

- after SINGER and SMITH (9) (modified) for effective stack heights greater than 40 m.

This procedure of vertical differentiation of dispersion parameters allows to take into consideration the vertical variations of roughness and stability effects.

TURNER class	F	f	G	g
2	1.21	0.76	0.05	1.28
3	0.86	0.77	0.09	1.10
4	1.25	0.69	0.72	0.74
5, 6	0.57	0.73	0.83	0.59

Coefficients of the diffusion parameters after McElroy and Pooler for effective stack heights $H \leqslant 40$ m

TURNER class	F	f	G	g
2	0.40	0.91	0.28	0.92
3	0.36	0.86	0.26	0.80
4	0.32	0.78	0.30	0.69
5, 6	0.31	0.71	0.15	0.64

Coefficients of the diffusion parameters after Singer and Smith (modified) for effective stack heights $H > 40$ m

3. Results of model calculations using the NATO /CCMS common data basis for the 'Test-City'

The GAUSSian plume model described above has been applied to the 'Standard Data Base' given in Techn. Doc. M. P. 2/1975 2.4 G.

From the results of the source-oriented version isopleths for the annual mean values of the SO_2-ground-level-concentration within the 'Test-City' have been derived; they can be found in Fig. 1.

The application of the receptor-oriented version yielded estimates of annual mean SO_2-ground-level concentrations for the six given receptor sites (see Table 1) and the cumulative frequency distributions of total SO_2-concentrations for these receptor locations (see Fig. 2 a to 2 f).

Receptor Number	Receptor Coordinates (km)		Annual mean value of SO_2-ground-level concentration ($\mu g/m^3$)
	East	North	
1	22.29	26.53	66.8
2	28.25	28.15	99.0
3	24.76	28.98	81.0
4	16.00	27.00	52.4
5	19.00	32.00	38.0
6	34.00	27.00	42.1

Table 1: Estimates of annual mean SO_2-ground-level-concentrations for six given receptor sites.

4. Sensitivity studies

An important step in the direction of model standardization is the evaluation of sensitivity analyses, as has been pointed out in (10).

The intention of a sensitivity analysis is

- to ascertain those parameters which mainly effect the model results,
- to estimate the error band width in the calculated concentration values due to uncertainties in these parameters,
- to make out those points of weakness where further studies should be initiated.

A sensitivity analysis can be performed by two slightly different methods

- by analytical investigation of error equations using the formal definition of 'Sensitivity' as the partial derivative of the concentration equation with respect to parameters and input data (see e.g. (11)),
- by the more experimental way of looking at incremental changes in model output resulting from an incremental change in input (see e.g. (12)).

The second method seems to be more appriate for such complex cases like multiple-source urban diffusion models.

A combination of both has been applied in (13) and has also been the basis for this study.

4.1 Sensitivity analysis of a concentration field with respect to the effective stack height

In this chapter we present a brief outline of (13) in which a sensitivity analysis with respect to the

effective stack height has been undertaken. The work done by MASSER and HAMMERLE (14) is a step in the same direction.

The sensitivity S_H of a GAUSSian plume ground-level concentration field with respect to variations in the effective stack height H is given by

$$S_H := \frac{\partial \chi}{\partial H} = - \frac{H}{\sigma_z^2} \chi$$

which represents a complicated function of the source distances x and y, of atmospheric stability and surface roughness, and of the effective stack height itself.

The derivative of S_H with respect to the source distance x for fixed effective stack height yields with

$$g \left[\frac{H^2}{\sigma_z^2} - 3 \right] - f = 0$$

a condition for the position of maximal sensitivity $S_{H,\,max}$ of the concentration distribution beneath the plume axis.

Here, f and g are the exponents in a power law for the dispersion parameters and

$$\sigma_y = F\, x^f; \qquad \sigma_z = G\, x^g.$$

Under the similarity assumption of dispersion in y- and z-direction

$$\frac{1}{\sigma_y} \frac{\partial \sigma_y}{\partial x} = \frac{1}{\sigma_z} \frac{\partial \sigma_z}{\partial x}$$

which is often applied in diffusion theory, we obtain

$$f = g,$$

and the condition above can be simplified to

$$\sigma_z = \frac{H}{2} \quad \text{for } x(S_{H,\,max}).$$

Under the same assumption the position of maximal ground-level concentration is given by

$$\sigma_z = \frac{H}{\sqrt{2}} \quad \text{for } x(\chi_{max}).$$

The qualitative behaviour of the functional dependence of sensitivity S_H and concentration upon source distance is characterized by the fact that the region of maximal sensitivity with respect to the effective stack height coincides with the region of the biggest concentration changes just ahead of the position of maximal concentration.

The assessment of calculated concentration values and the requirements concerning the accuracy of effective stack height data should be derived on the basis of this result which has been quantified in Fig. 3 using an isotropy assumption for turbulent diffusion.

Fig. 3 shows the locations, defined through the ratio H/σ_z, for which sensitivity S_H and ground-level concentration χ have decreased to a given fraction Br of their maximal values.

$$Br_S = S_H\left(\frac{H}{\sigma_z}\right) / S_{H,\,max};$$

$$Br_\chi = \chi\left(\frac{H}{\sigma_z}\right) / \chi_{max}.$$

4.1.1 Plume rise of space heating

For space heating only few data and assumptions concerning plume rise are available and, furthermore, the nearest down-wind grid-point of the model will generally be near the region of maximal sensitivity S_H. Thus, here the uncertainty might be considerable, though this effect is partly smeered out due to the statistical element introduced by the area source representation.

To find out the order of magnitude of possible errors due to plume rise of space heating we used the multiple-source urban diffusion model described in chapter 2, and varied the underlieing assumption concerning the plume rise of space heating. In Fig. 4 calculated annual mean SO_2 ground-level concentrations from space heating are presented for selected receptor sites.

The left numbers are mean values calculated by use of empirical, stability- and wind speed- dependent plume rise estimations, (see chapter 2), the right numbers are mean values neglecting this plume rise of area sources. The difference is of the order of 20 % in ground-level concentration.

4.1.2 Plume rise of singular emittents

The problem of choosing an adequate plume rise equation for singular emittents has already been subject of several detailed studies. MOSES and KRAIMER (15) demonstrated that the range of applicability of most of the known plume rise equations depends upon

- the type of the source (momentum or buoyant plume),

- the magnitude of the heat emission,
- atmospheric stability.

The sensitivity with which a concentration field reacts on variations of the effective stack height has been studied e.g. by MASSER and HAMMERLE (14).

Because results concerning the effect of the chosen plume rise on the concentration field are well documented, we want, to draw at this place, the attention to a point not as well-known. The definition of the mean wind speed used in the GAUSSian plume equation and in the plume rise formula (here MOSES and CARSON's formula for neutral stratification) differs from model to model. Sometimes, the mean wind speed in the physical or in the effective stack height has been used or a value determined by integration of a power law for the vertical wind profile over the effective or two times the effective stack height. Fig. 5 compares the annual mean concentration field due to singular emittents using the wind speed in the physical stack height (left number) and mean wind speed determined by integration over two times th effective stack height (right number). The differences are of the order 10 to 20 % in ground level concentration.

From physical arguments based on the continuity condition,

$$\int_{-\infty}^{+\infty} dy \int_{0}^{\infty} dz \; \bar{u} \; \chi(x,y,z) = Q \quad \text{for each } x > 0,$$

with the help of which the GAUSSian plume solution has been derived from the diffusion equation, and

due to the fact that in several works on plume rise problems measurements of the mean wind speed in the physical stack height have been used to derive a plume rise formula we would recommend to apply the mean wind speed in the physical stack height for a standardized GAUSSian plume model.

4.2 Sensitivity analysis with respect to dispersion parameters

The analytical expression for the sensitivity of the GAUSSian plume equation with respect to the dispersion parameters
σ_y and σ_z are given by

$$S_{\sigma_y} = \frac{1}{\sigma_y}\left[\frac{y^2}{\sigma_y^2} - 1\right]\chi,$$

$$S_{\sigma_z} = \frac{1}{\sigma_z}\left[\frac{H^2}{\sigma_z^2} - 1\right]\chi.$$

A detailed discussion of these expressions shows that great importance has to be attached to the choice of a suitable set of dispersion parameters. This has also been emphasized by WEBER and PASQUILL (16).

Besides the fundamental points of view outlined in (16) it has to be noticed that the various tracer experiments for the determination of dispersion parameters have been planned and performed

- under different topographic and roughness conditions,
- in distinct climatological regions,
- uncompatible stability classification schemes.

Nevertheless, in most urban diffusion models different sets of dispersion parameters and distinct stability

classification schemes are more or less arbitrarily combined and assigned to arbitrary topographic and roughness conditions.

In view of this fact we tested the variability of the immission climatological field with respect to the choice of the set of dispersion parameters. Inter alia due to greater surface roughness the Jülich dispersion parameters (17) are considerably larger than those determined by SINGER and SMITH (9). Both parameter sets result from experiments in approximately the same height of 100 m; nevertheless, the Jülich dispersion parameters approach those by McELROY and POOLER (8) (near-ground experiments) due to this greater roughness. As a consequence the position of maximum concentration due to a singular emittent comes closer to the source's position with considerably higher concentration values.

This effect can even clearly be seen in the field of the annual mean SO_2-ground level concentrations due to <u>all</u> singular emittents in the Frankfurt area. To elucidate this observation we outline position, physical stack height, and source strength of some of the biggest singular emittents in Fig. 6.

In the vicinity of an industrial area (south-west region of the Test-City) the annual mean SO_2-ground level concentrations (Fig. 7) due to singular emittents are about 50 % higher when calculated with the Jülich dispersion parameters than those when making use of SINGER and SMITH's data. The differences, however, are much more pronounced in the resulting cumulative frequency distribution for a receptor site in this area (Fig. 8).

The consequence is, that a suitable set of dispersion parameters has to be chosen in such a way that the special requirements of the region under concern are to be taken into account, and that there exists a great error band width due to uncertainties in dispersion parameters.

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Fig. 1: Calculated isopleths of annual mean SO_2-ground level concentrations ($\mu g/m^3$)
(singular emittents plus area sources)

Fig. 2: Cumulative frequency distribution of total SO_2-ground level concentrations for the receptor site

2a : (22.29; 26.53)
2b : (28.25; 28.15)
2c : (24.76; 28.98)
2d : (16.00; 27.00)
2e : (29.00; 32.00)
2f : (34.00; 27.00)

Fig. 3: Locations (defined through the ration H/σ_z), for which sensitivity S_H and ground-level concentration χ have decreased to a given fraction Br of their maximal values.

Fig. 4: Calculated annual mean SO_2-ground level concentrations ($\mu g/m^3$) due to space heating

left number : using empirical, stability- and wind speed dependent plume rise estimations

right number: neglecting plume rise of area sources.

Fig. 5: Calculated annual means SO_2-ground level concentrations ($\mu g/m^3$) due to singular emittents mean wind speed determined from a power law

left number : in the physical stack hight

right number: by integration over two times the effective stack height

triangles: position of some of the biggest singular emittents

Fig. 6: Region of model application and positions of some of the biggest singular emittents

left number : physical stack height (m)
right number: source strength (kg SO_2/h)

Fig. 7: Calculated annual mean SO_2-ground level concentrations ($\mu g/m^3$) due to singular emittents

left number: using dispersion parameters from the JÜLICH experiments

right number: using SINGER and SMITH's dispersion parameters

triangles: position of some of the biggest singular emittents

Fig. 8: Cumulative frequency distribution for a receptor site in the vicinity of an industrial area

upper curve: using SINGER and SMITH's dispersion parameters

lower curve: using dispersion parameters from the JÜLICH experiments

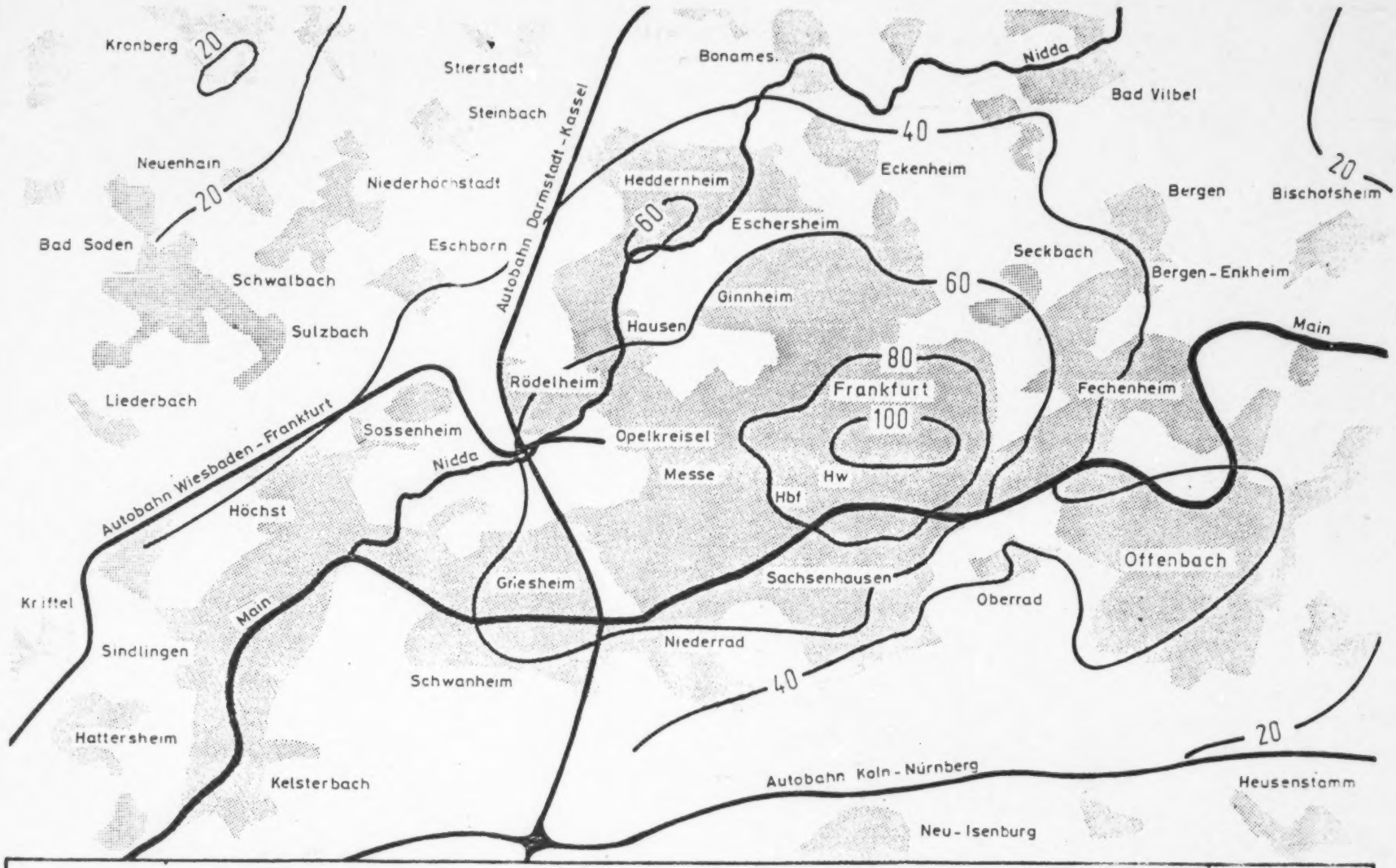


Fig. 1: Calculated isopleths of annual means SO_2-ground level concentrations ($\mu g/m^3$) (singular emittents plus area sources)

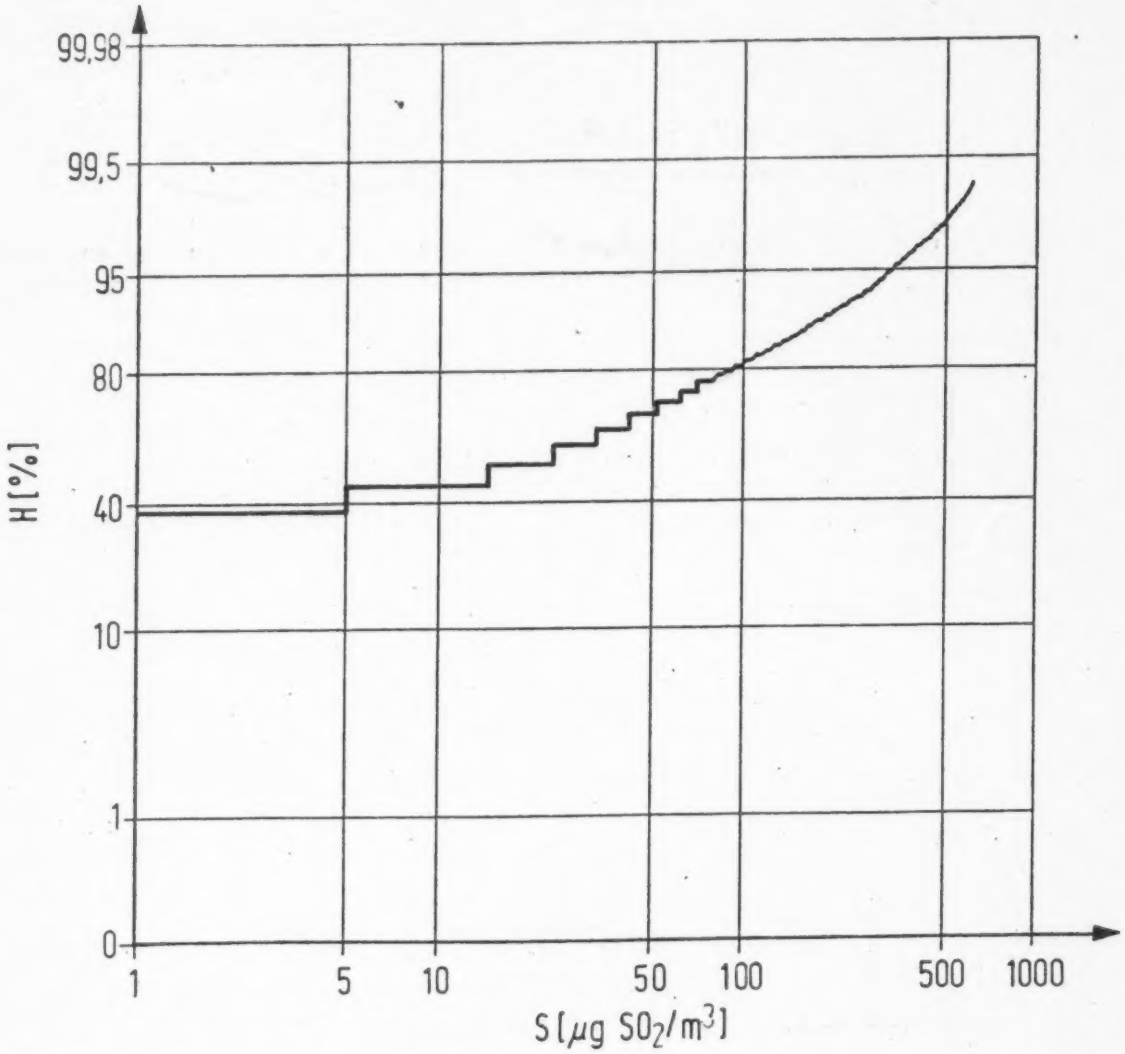


Fig. 2a: Cumulative frequency distribution of total SO_2-ground level concentrations for the receptor site (2229; 2653)

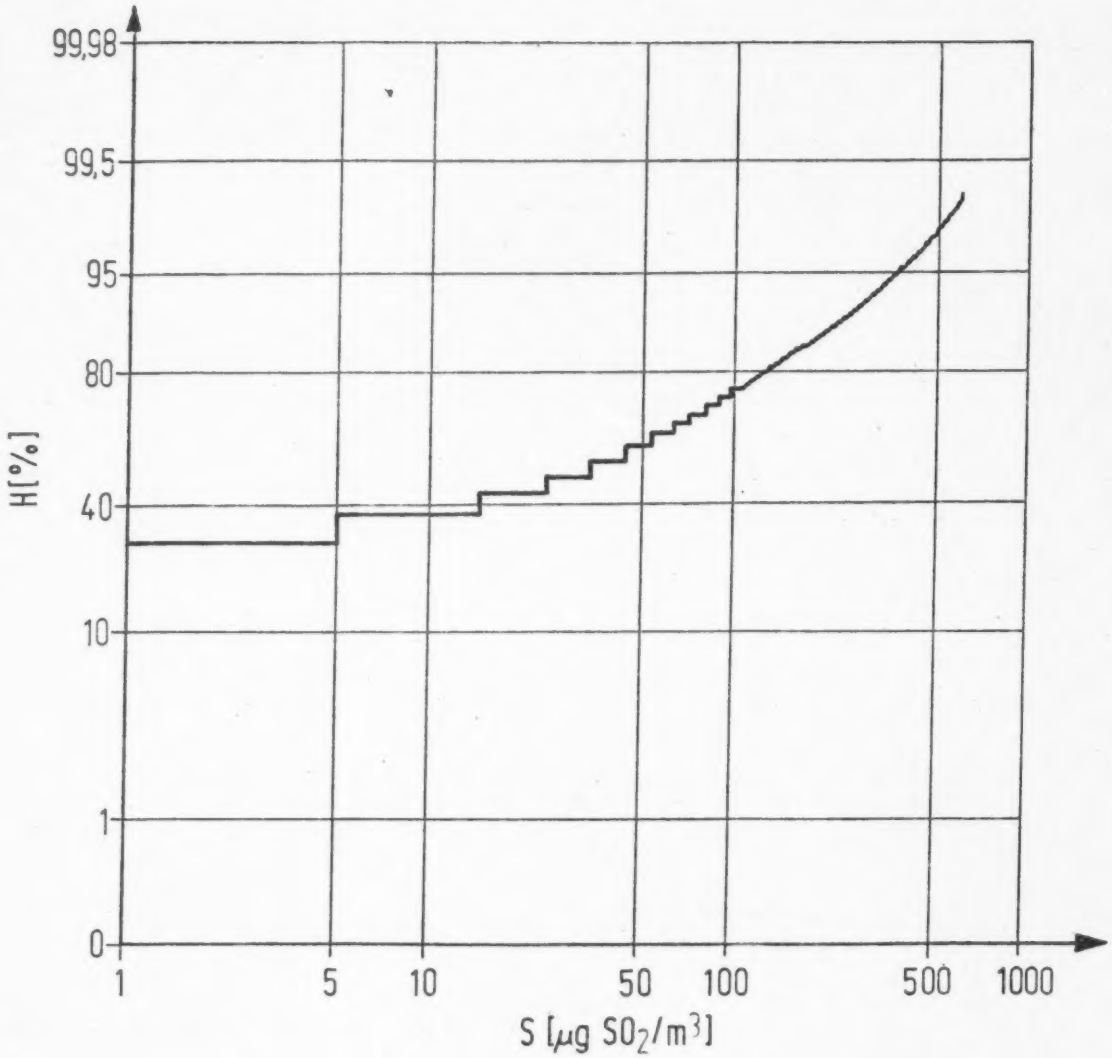


Fig. 2b: Cumulative frequency distribution of total SO_2-ground level concentrations for the receptor site (2825; 2815)

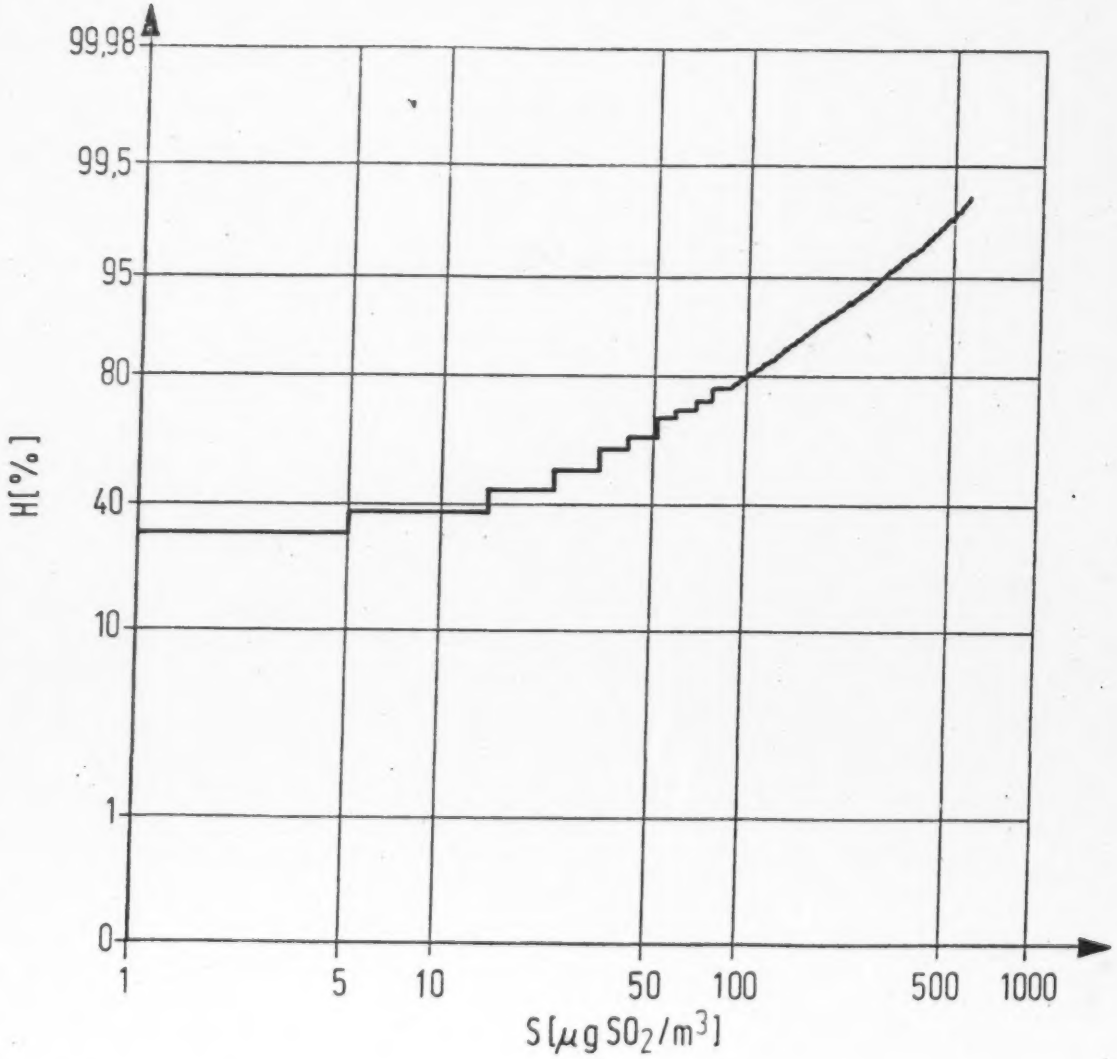


Fig. 2c: Cumulative frequency distribution of tota SO_2-ground level concentrations for the receptor site (2476; 2898)

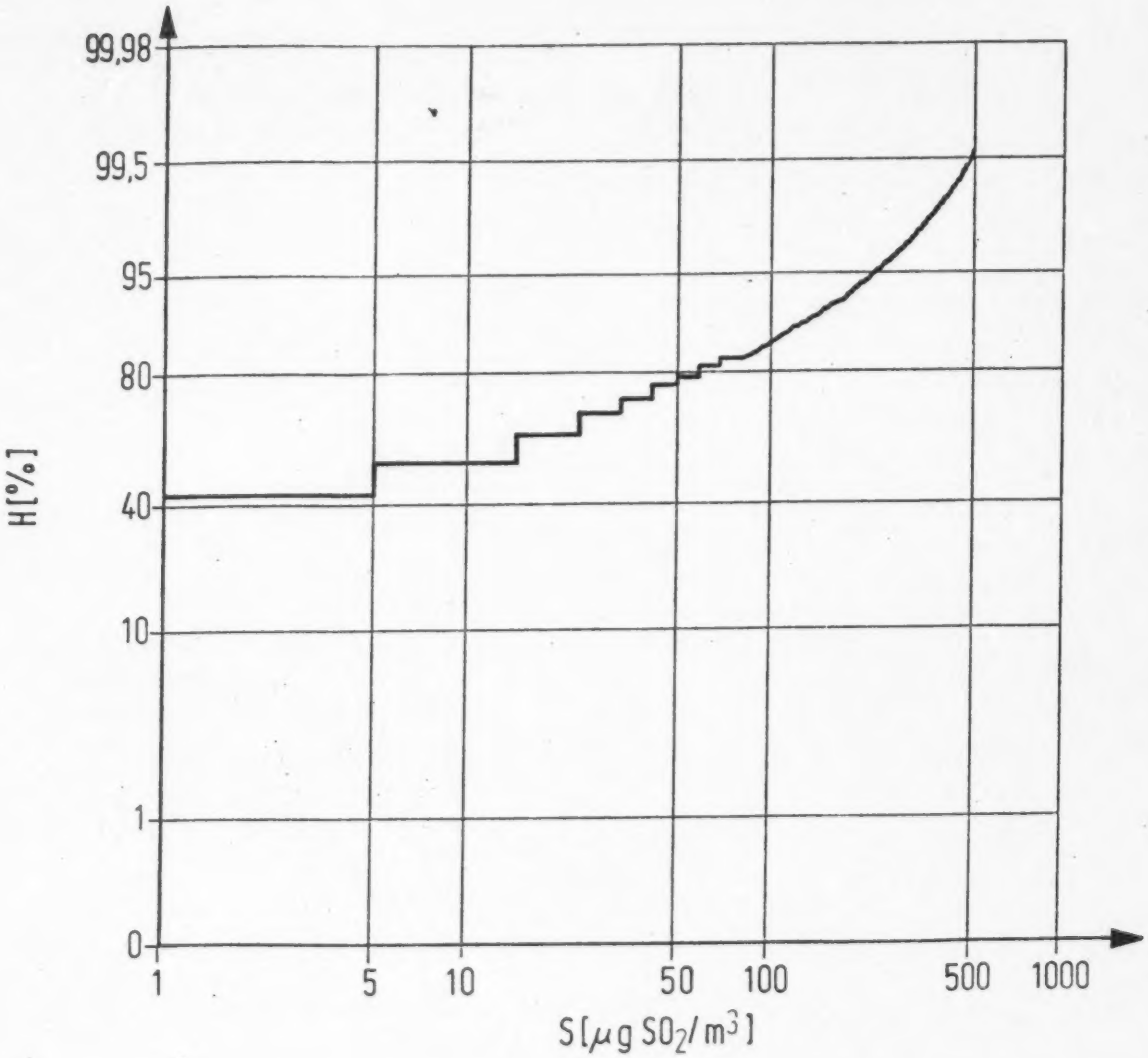


Fig. 2d: Cumulative frequency distribution of total SO_2-ground level concentrations for the receptor site (1600; 2700)

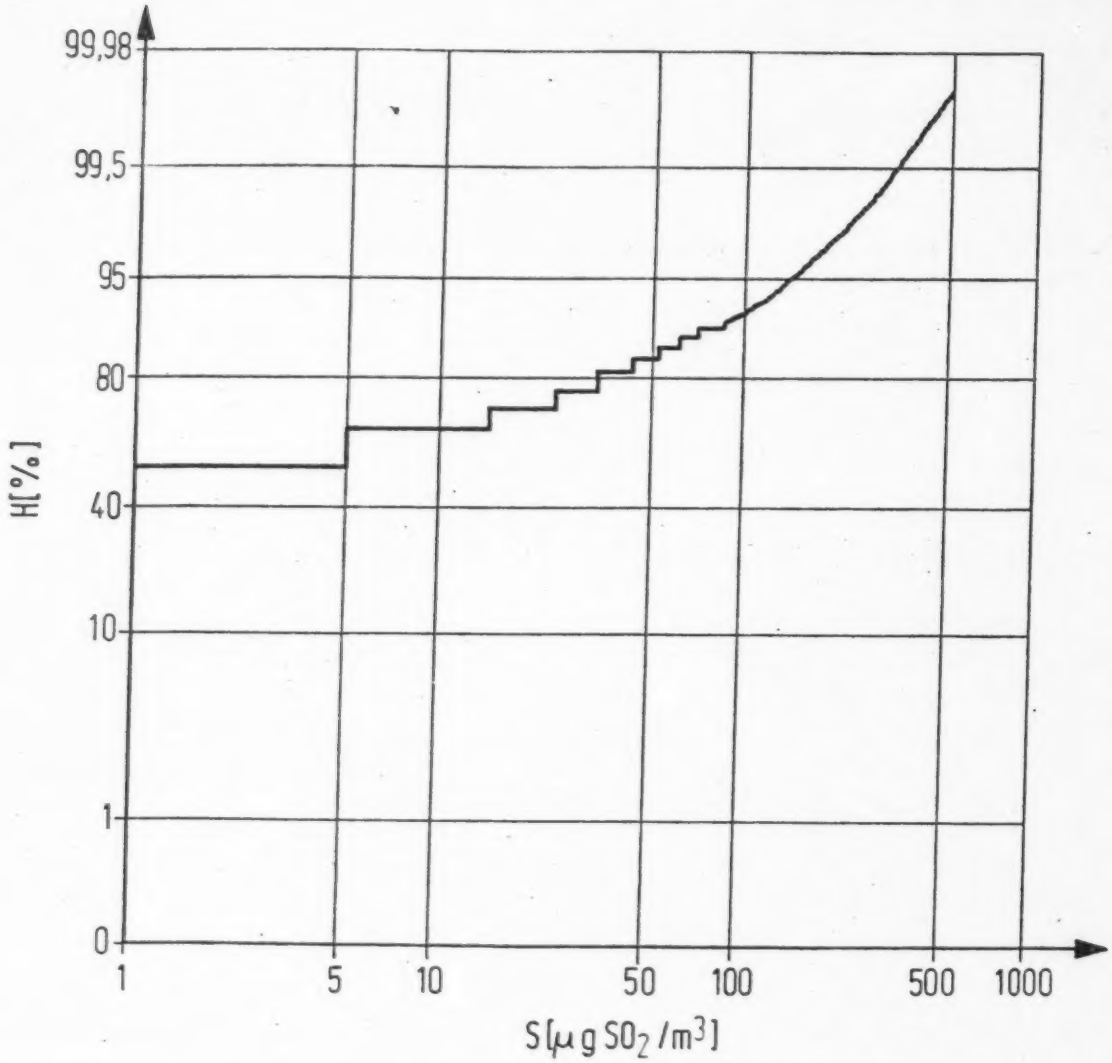


Fig. 2e: Cumulative frequency distribution of total SO_2-ground level concentrations for the receptor site (1900; 3200)

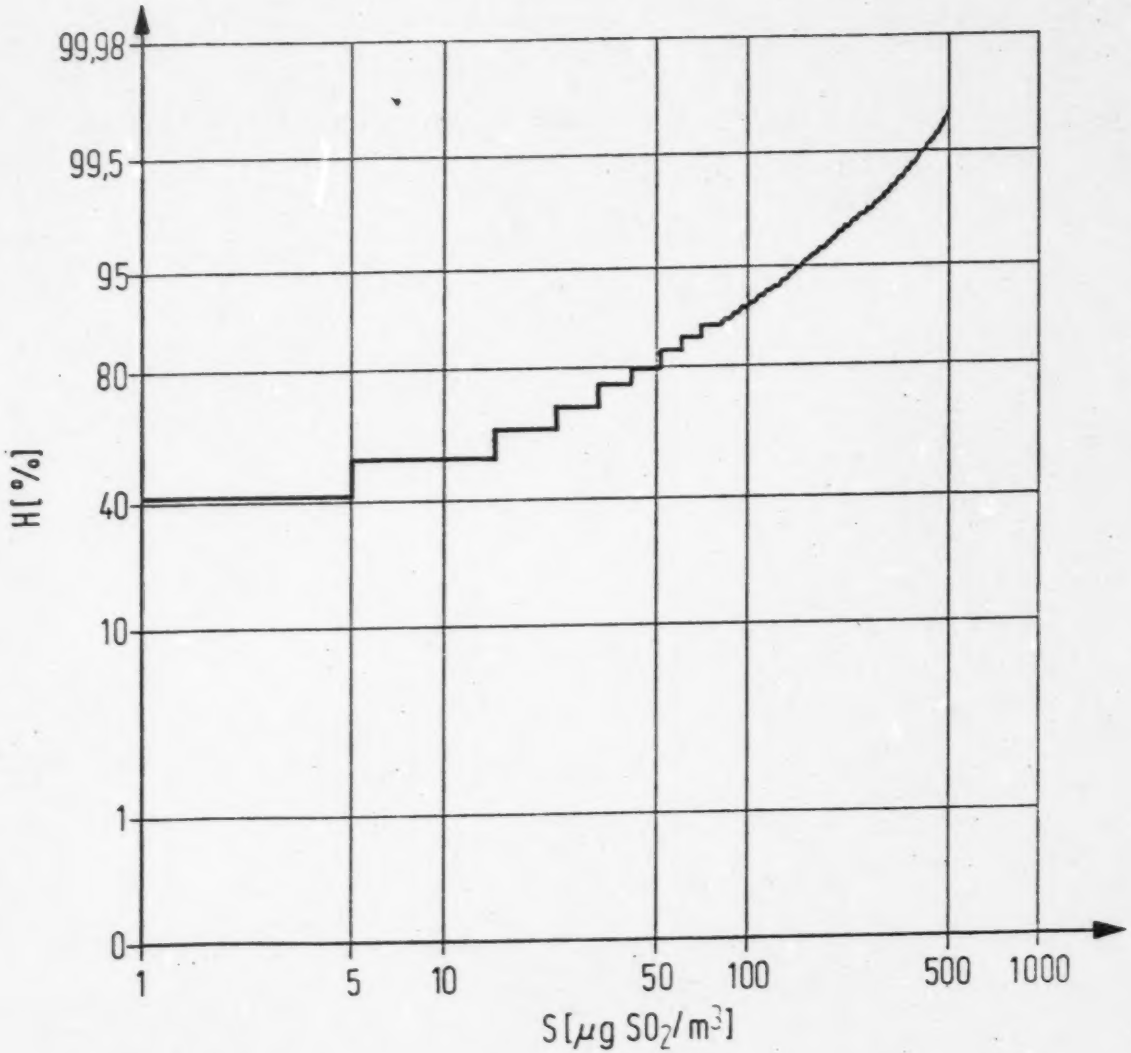


Fig. 2f: Cumulative frequency distribution of total SO_2-ground level concentrations for the receptor site (3400; 2700)

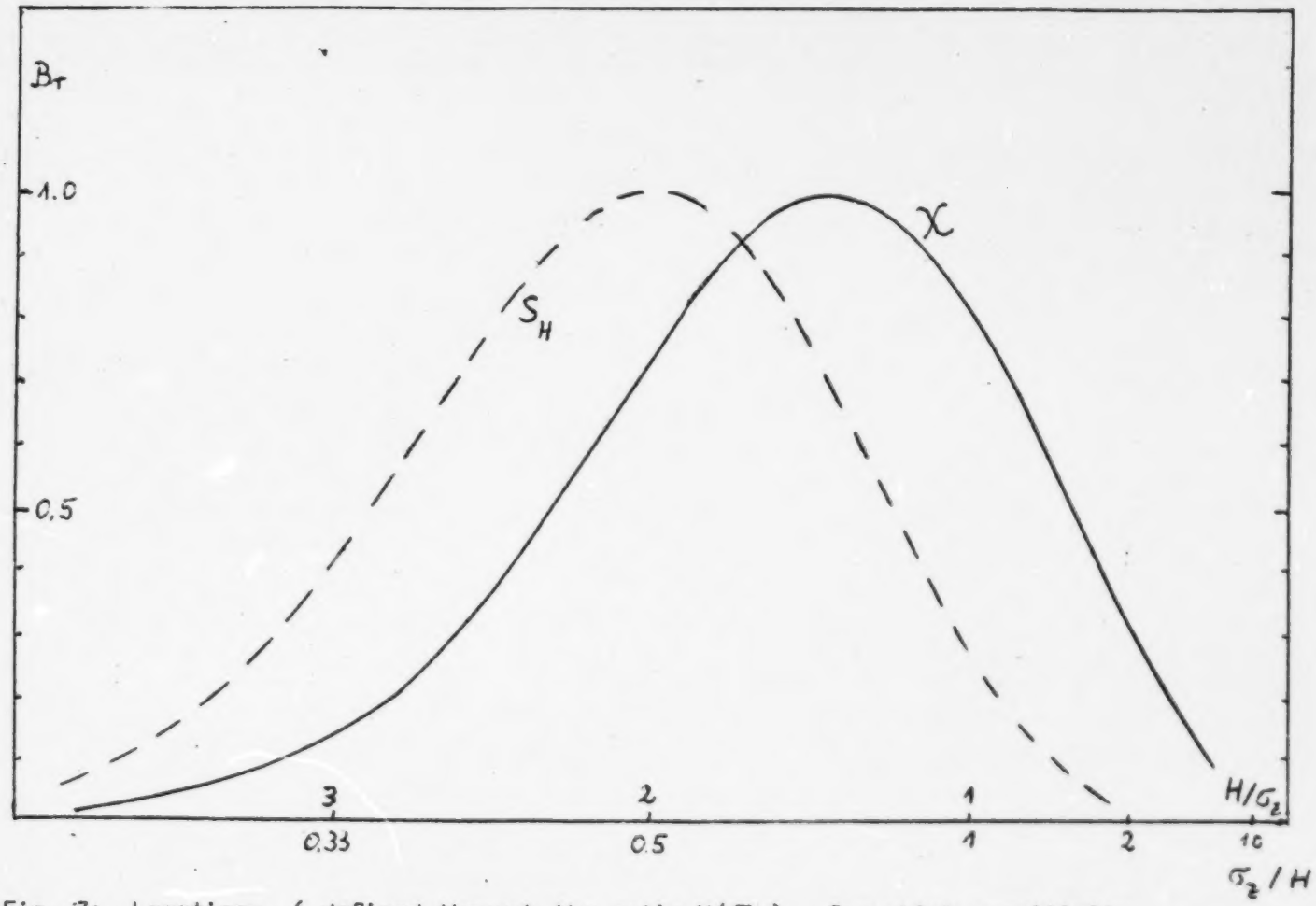


Fig. 3: Locations (defined through the ratio H/σ_z), for which sensitivity S_H and ground-level concentration χ have decreased to a given fraction Br of their maximal values

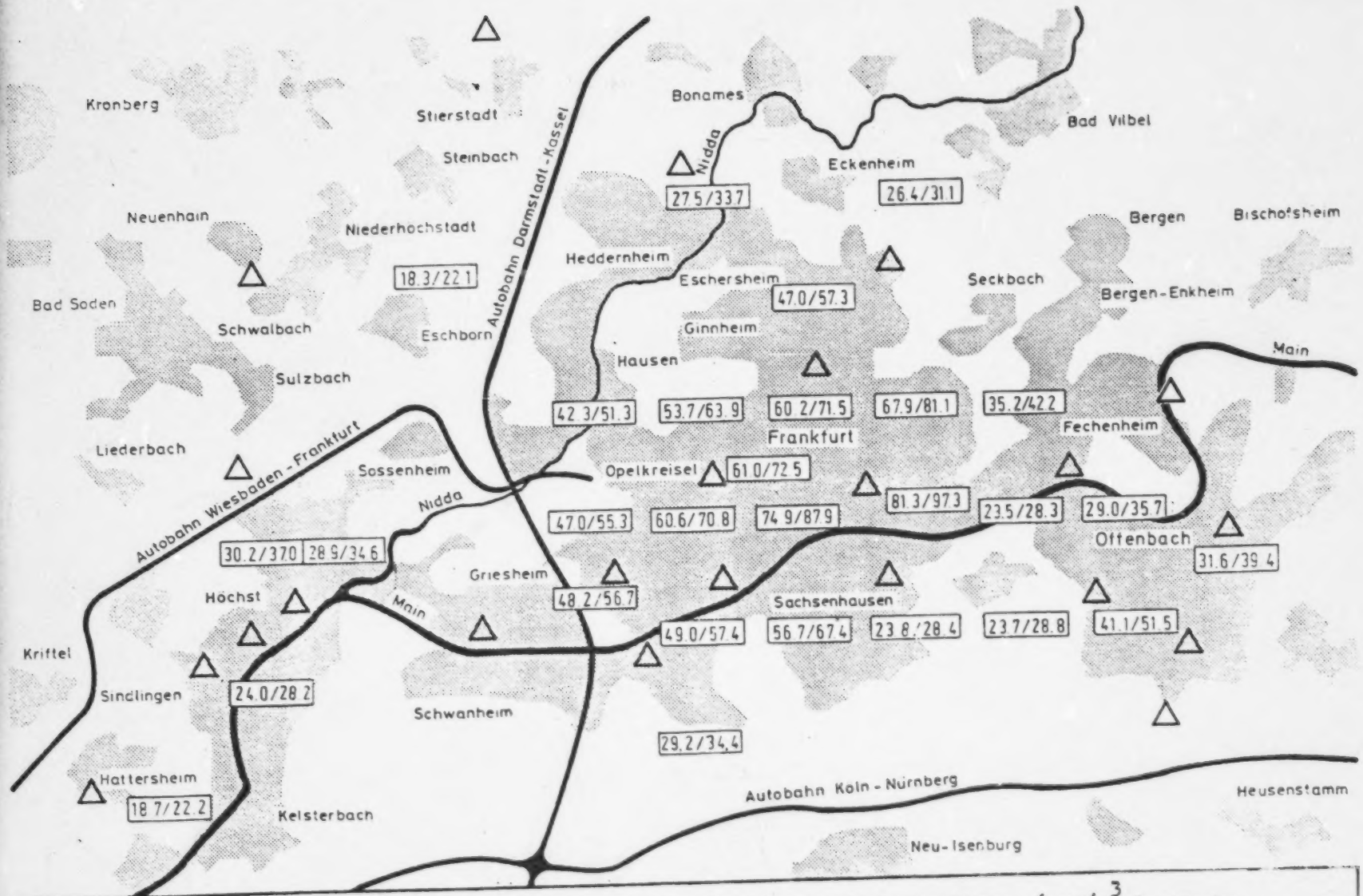


Fig. 4: Calculated annual mean SO_2-ground level concentrations ($\mu g/m^3$) due to space heating
left number : using empirical stability- and wind speed dependent plume rise estimations
right number: neglecting plume rise of area sources

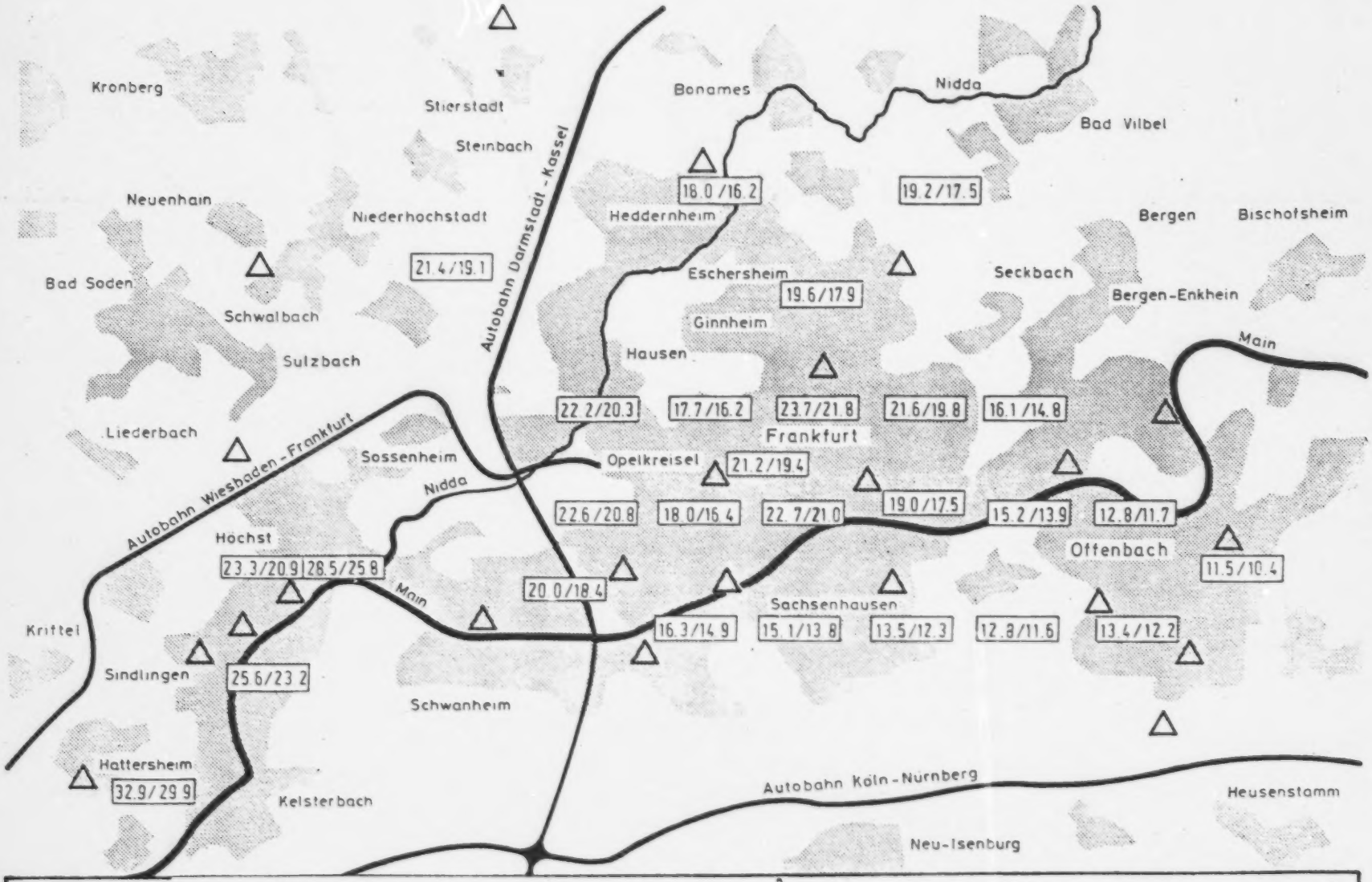


Fig. 5: Calculated annual mean SO_2-ground level concentrations ($\mu g/m^3$) due to singular emittents in the Frankfurt area; mean wind speed determind from a power law. left number: in the physical stack hight
right number: by integration over two times the effective stack hight
triangels: position of some of the biggest singular emittents

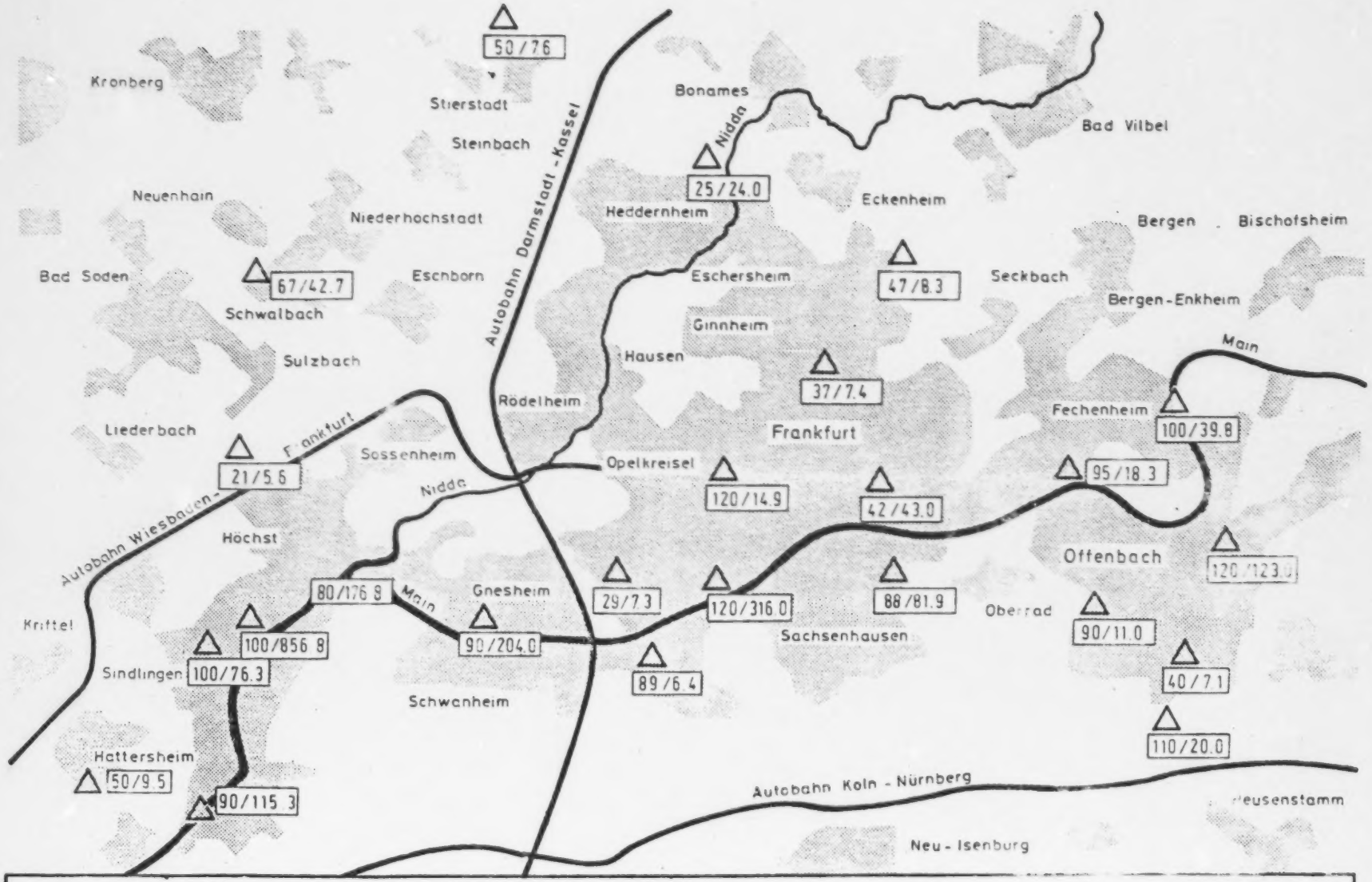


Fig. 6: Region of model application and positions of some of the biggest singular emittents.
left number: physical stack height (m)
right number: source strength (kg SO_2/h)

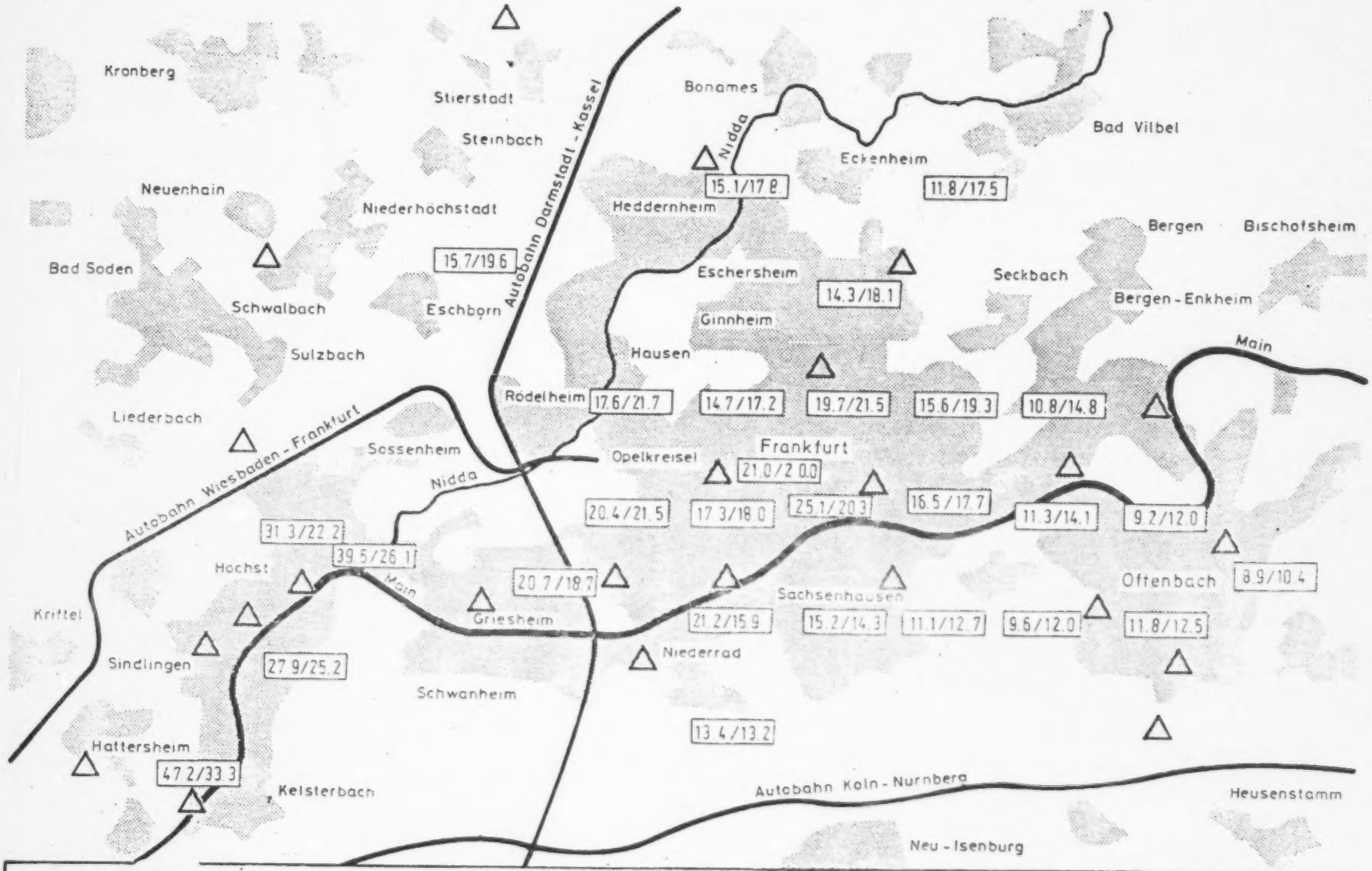


Fig. 7: Calculated annual means SO_2-ground level concentrations ($\mu g/m^3$) due to singular emittents
left number: using dispersion parameters from the Jülich experiments
right number: using SINGER and SMITH's dispersion parameters
triangles: position of (ne of the biggest singular emitte s

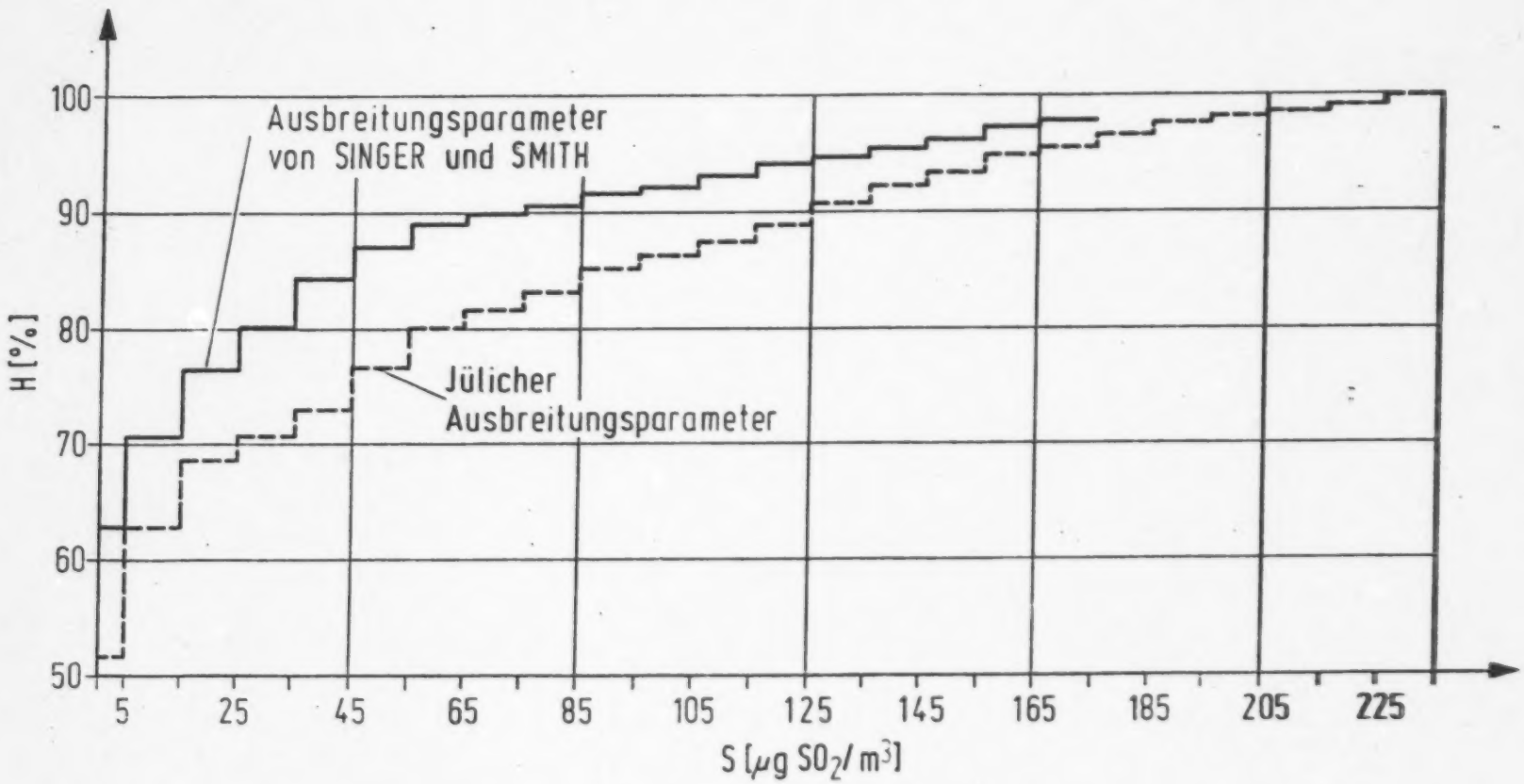


Fig. 8: Cumulative frequency distribution for a receptor site in the vicinity of an industrial area
upper curve: using SINGER and SMITH's dispersion parameters
lower curve: using dispersion parameters from the JÜLICH experiments

Practical Demonstration
of
Urban Air Quality Simulation Models

Model Results
of

Kropp; Fed. Rep. of Germany (2x)

TÜV Rheinland multiple-source dispersion model

L. Kropp, TÜV Rheinland, Köln, Germany

Summary

Model calculations were performed for the sources of a test city, i. e. industrial as well as domestic heatings SO_2-emissions were taken into respect. On the basis of a one year joint frequency distribution annual mean values for a grid system of 1 x 1 km and ground load frequency distributions were calculated using the diffusion parameters of Mc Elroy/Pooler and Singer/Smith on the one hand and those of Vogt on the other each combined with adequate turbulence classes .

The results differ by less than 20 % in general and about 30 % in extreme cases. A barrier layer of 1000 m shows changes of the annual mean concentrations of less than 2 $\mu g/m^3$.

Model description

The model used is designed to calculate frequency distributions of ground level concentrations; a simplified model estimates annual mean values only in a much shorter time (about 10 % than for the extensive model).

Model characteristics are:

- diffusion is described by Gaussian plume over flat terrain
- plume rise is calculated via the formula of Moses and Carson
- total reflection at boundary layers (ground and inversion layer)

- no deposition or chemical transformation
- no wind shear is taken into account
- vertical wind (speed) profile follows a power law
- the effective wind speed for dispersion corresponds to the average between 10 m height and effective source height
- wind speed is classified into 10 representative values (1, 1.5, 2, 3, 4.5, 6, 7.5, 9, 11, 13.5 m/s)
- wind direction is taken as constant within 10 degree sectors and is varied therein in 2,5 degree steps
- turbulence situation is classified following Klug/Manier and Turner, respectively
- turbulence is taken into account using the diffusion parameters of Vogt and Mc Elroy/Pooler - Singer/Smith, respectively
- point sources of a strength less than 1 kg/h (as annual average) are converted into area sources together with domestic heating area sources
- area sources are replaced by a number of point sources (1 km x 1 km → 400 point sources)
- emission height of area sources is classified within 4 different representative heights (7.5, 15, 25, 35 m)
- time dependant sources are described by two or four time periods

Results

The model calculations are presented as isolines of annual mean values for

- diffusion parameters of Mc Elroy/Pooler and Singer/Smith with Turners turbulence classification
- diffusion parameter of Vogt with Kluq/Manier turbulence classification

Additionally for 6 selected points the cumulative frequency distributions are displayed.

Furthermore an inversion layer (total reflection) at a height of 1000 m was inserted in a set of runs.

The results are as follows:

fig. 1. Isolines of annual mean concentrations for parameters of Mc Elroy/Pooler and Singer/Smith (no inversion layer)

fig. 2. Isolines of annual mean concentration for Vogt's parameters (no inversion layer)

fig. 3. as fig. 1 including inversion layer

fig. 4. as fig. 2 including inversion layer

fig. 5.-11. cumulative frequency distribution at 6 selected sites

Discussion of the results

There has been no calibration of the model.

The average values vary between 6 µg/m² at the outer border and 125 µg/m³ at maximum. The inversion layer influences the concentration values by less than 1.5 to 2 µg/m³.

The calculations for the two sets of diffusion parameters deviate by 30 % at maximum showing higher values if Vogt's parameters are used. The percentage deviations are larger in the border areas of the region under investigation.

A summary of the results at the 6 selected sites is given in tabs. 1 to 3

(tab. 1	annual means
tab. 2	95 percentile
tab. 3	99 percentile)

Köln, den 28.07.1977
936-dr.kr-dz

Dr. rer. nat. Kropp

Site	relative coordinates [m]	
	x (rechts)	y (hoch)
I	13.290	9.530
II	19.250	11.150
III	15.760	11.980
IV	7.000	10.000
V	10.000	15.000
VI	25.000	10.000

Tab. 1

Parameter Turbulence/class Inversion layer	Mc Elroy/Pooler bzw. Singer/Smith Turner		Polster/Vogt Klug/Manier	
		1000 m		1000 m
Site				
I	0.0789	0.0801	0.0960	0.0977
II	0.0663	0.0674	0.0725	0.0743
III	0.0907	0.0919	0.107	0.108
IV	0.0701	0.0714	0.0942	0.0960
V	0.0391	0.0403	0.0429	0.0449
VI	0.0457	0.0467	0.0541	0.0556

Tab. 2

Parameter Turbulence class Inversion layer	Mc Elroy/Pooler Singer/Smith Turner		Polster/Vogt Klug/Manier	
		1000 m		1000 m
Site				
I	0,311	0,313	0,422	0,423
II	0,251	0,254	0,293	0,296
III	0,339	0,340	0,451	0,451
IV	0,285	0,288	0,376	0,378
V	0,193	0,195	0,184	0,186
VI	0,164	0,167	0,211	0,214

Tab. 3

Parameter Turbulence class Inversion layer	Mc Elroy/Pooler Singer/Smith Turner		Polster/Vogt Klug/Manier	
		1000 m		1000 m
Site				
I	0,540	0,540	0,150	0,150
II	0,441	0,443	0,516	0,517
III	0,579	0,579	0,158	0,156
IV	0,474	0,480	0,644	0,645
V	0,377	0,378	0,346	0,346
VI	0,293	0,295	0,367	0,367

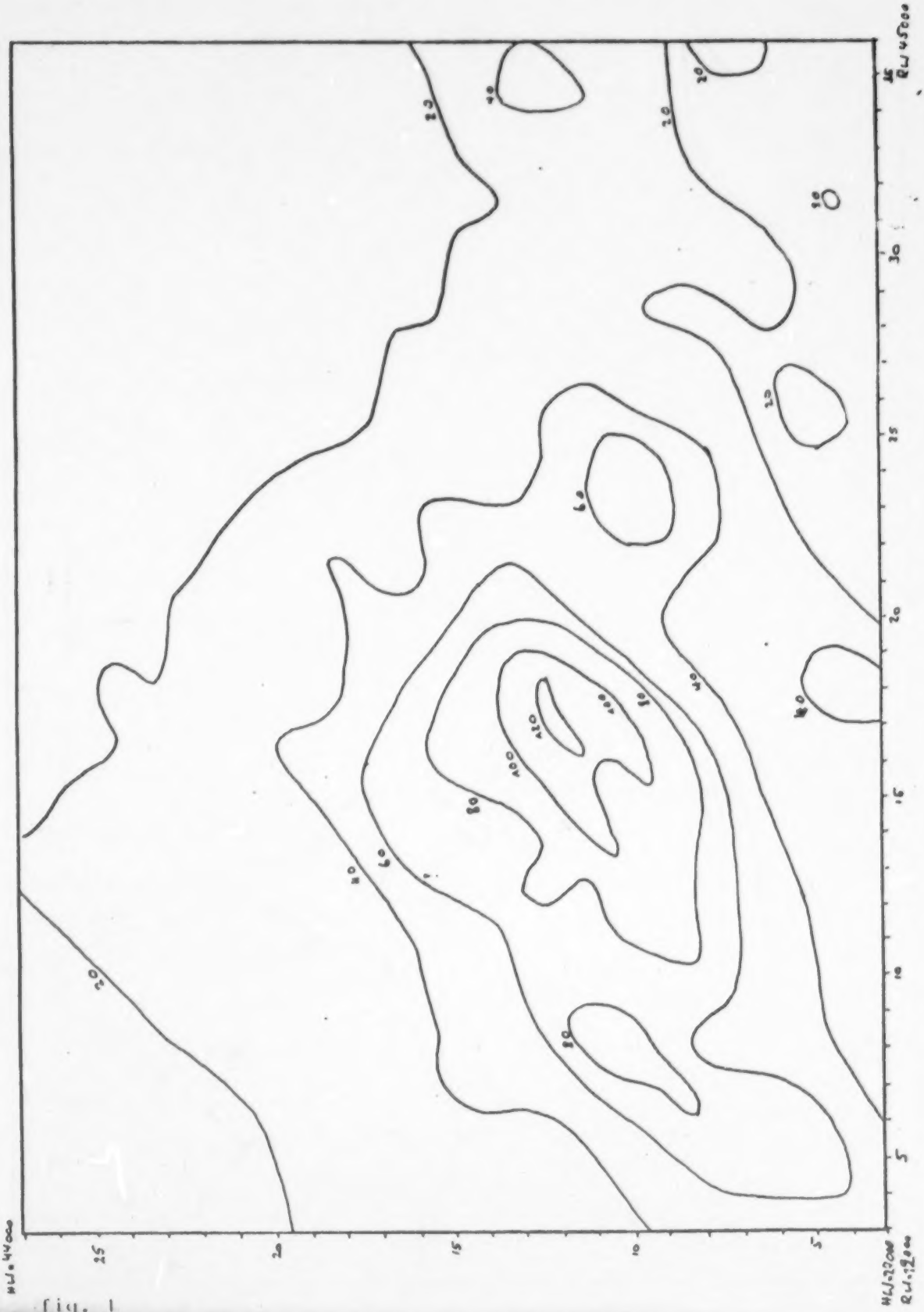


fig. 1

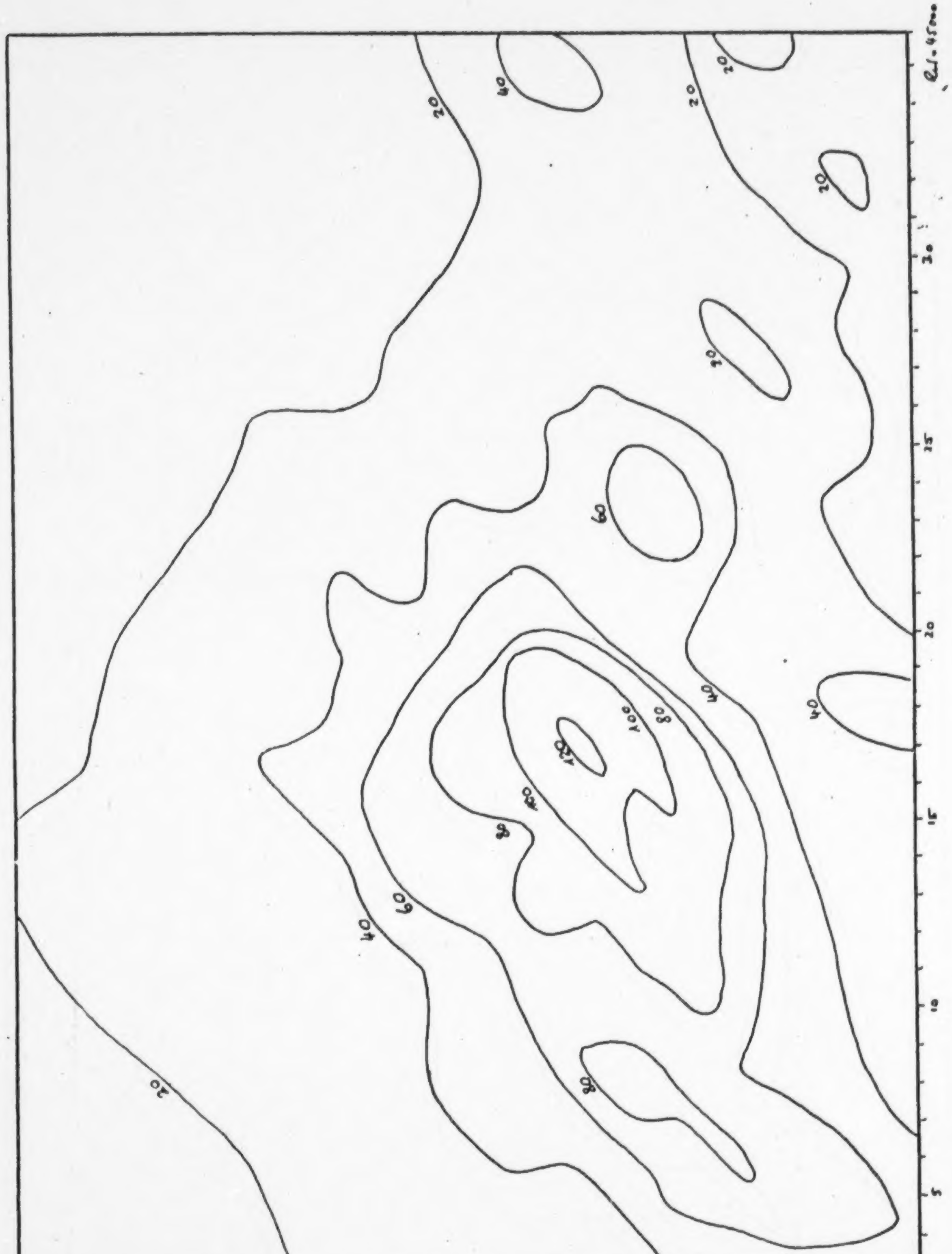


fig. 2

RW 45000
HW 20000
RW 42000
HW 74000
5
10
15
20
25
30
35
20
40
60
80
100

fig. 3

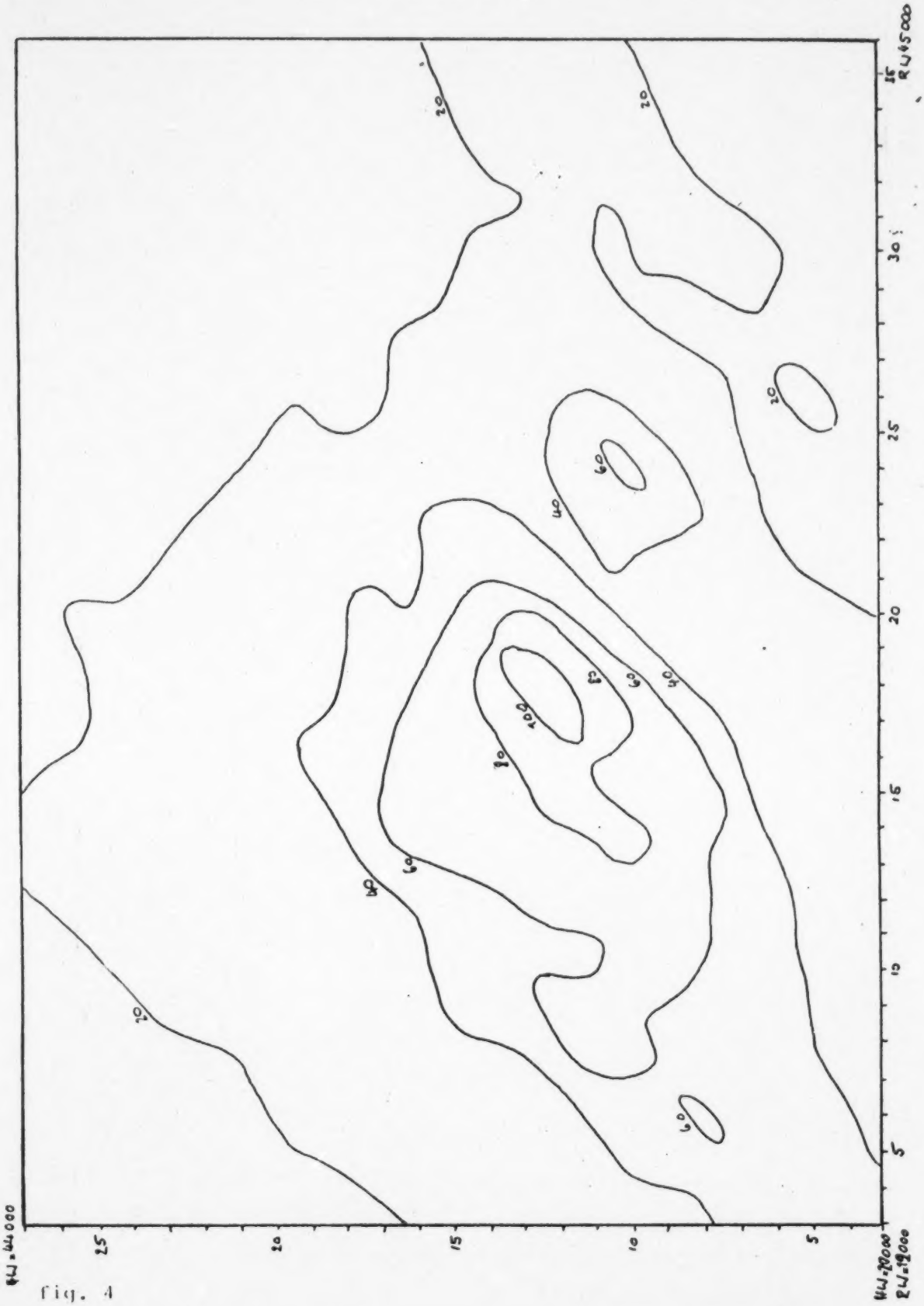
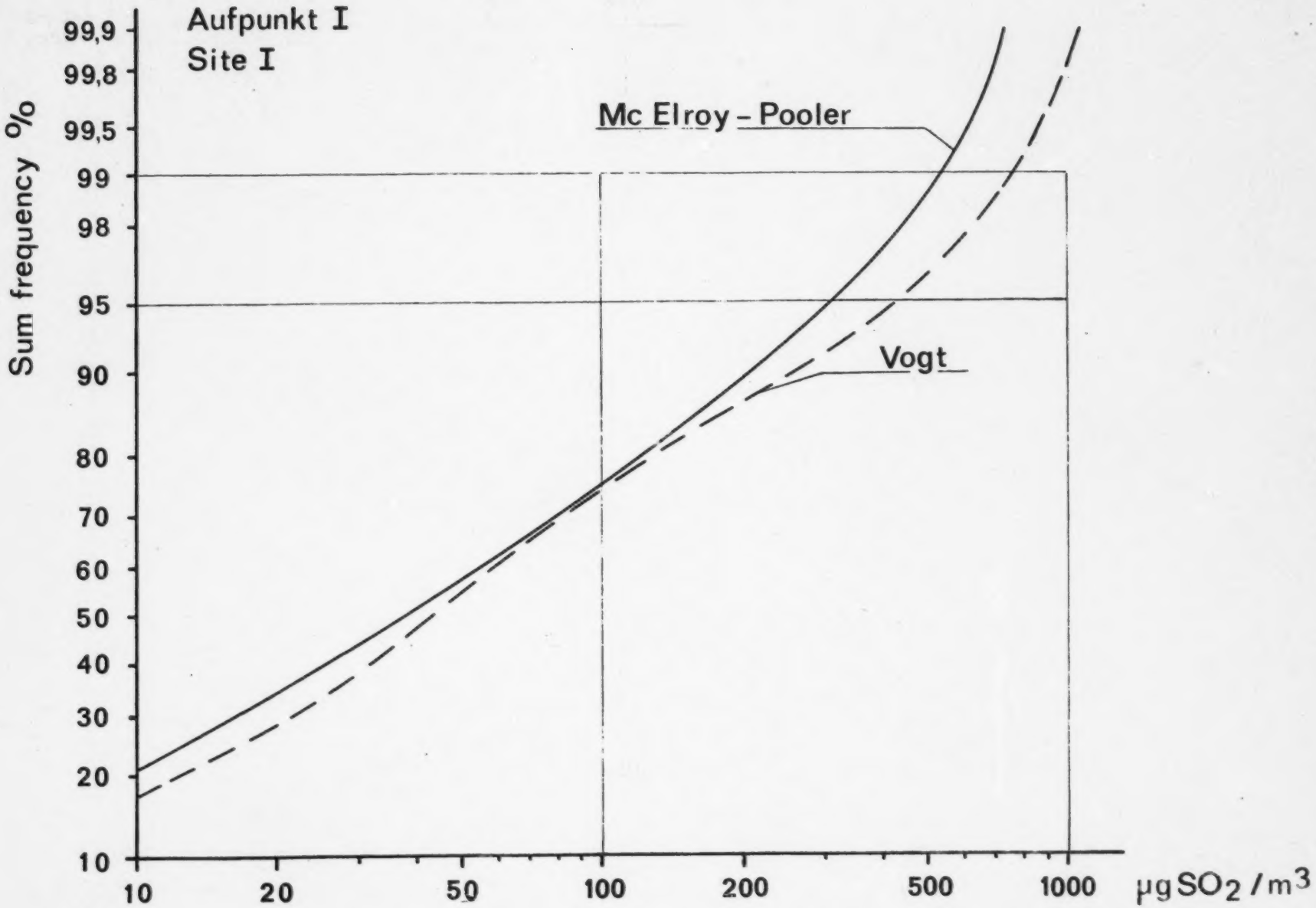
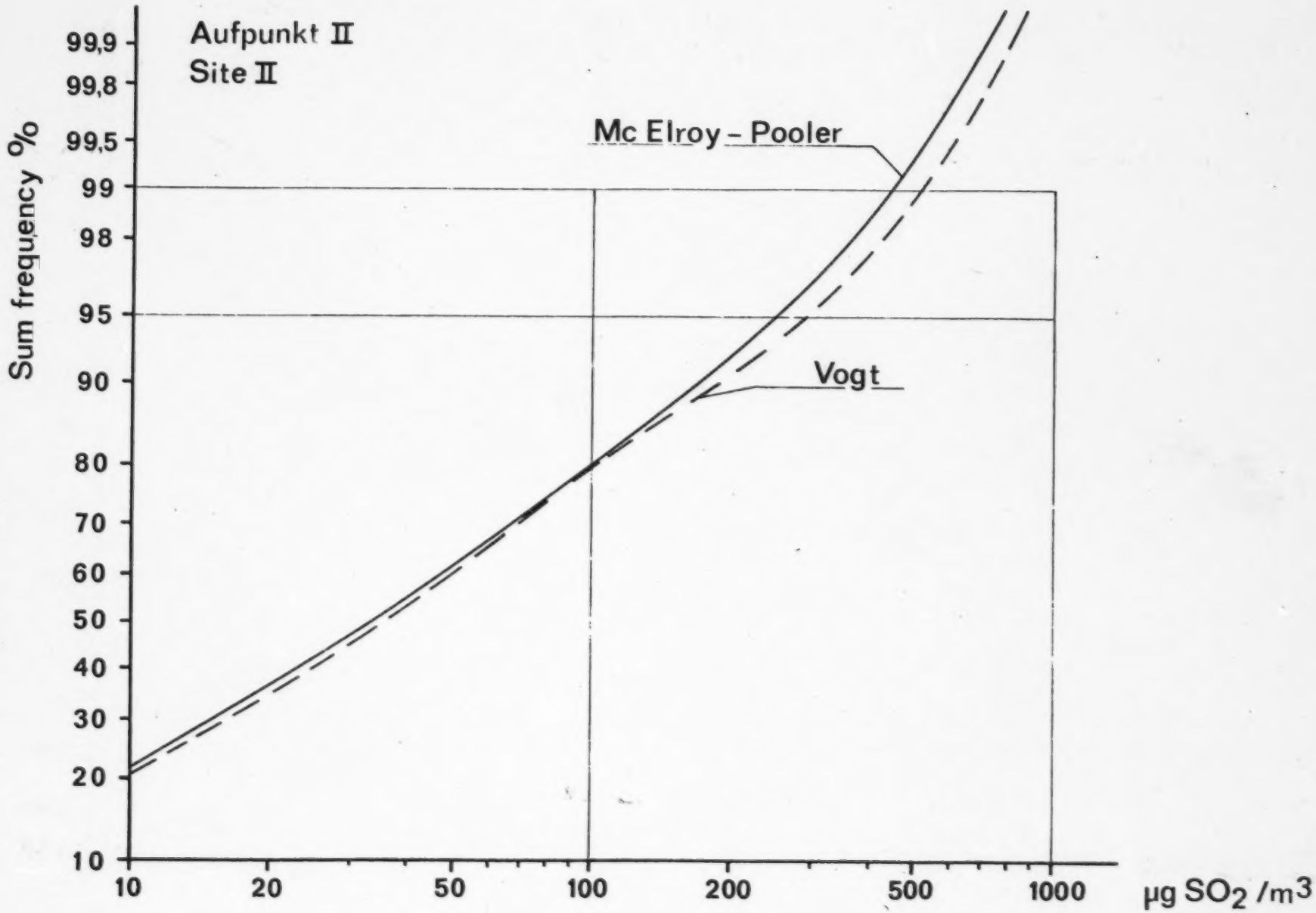
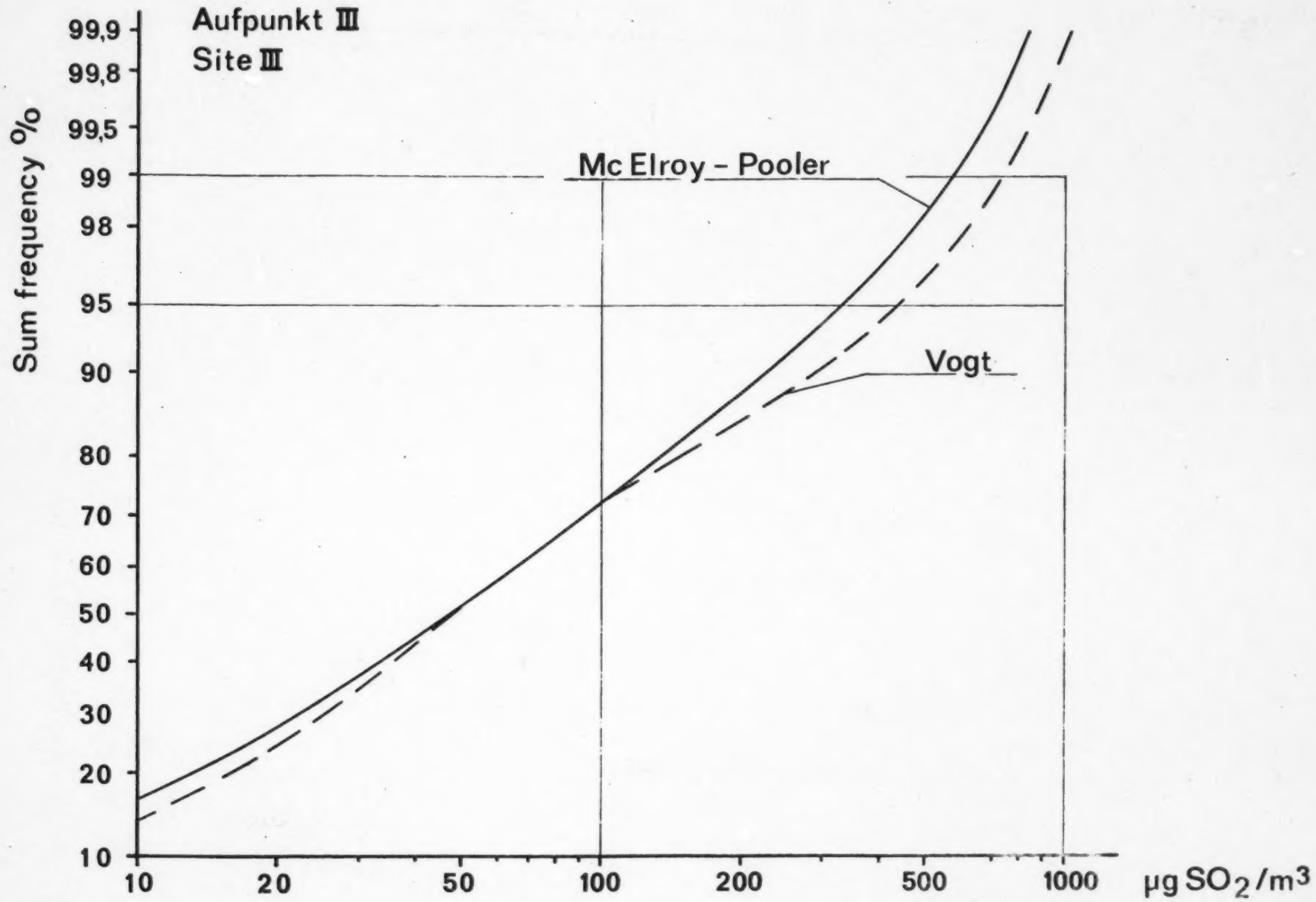
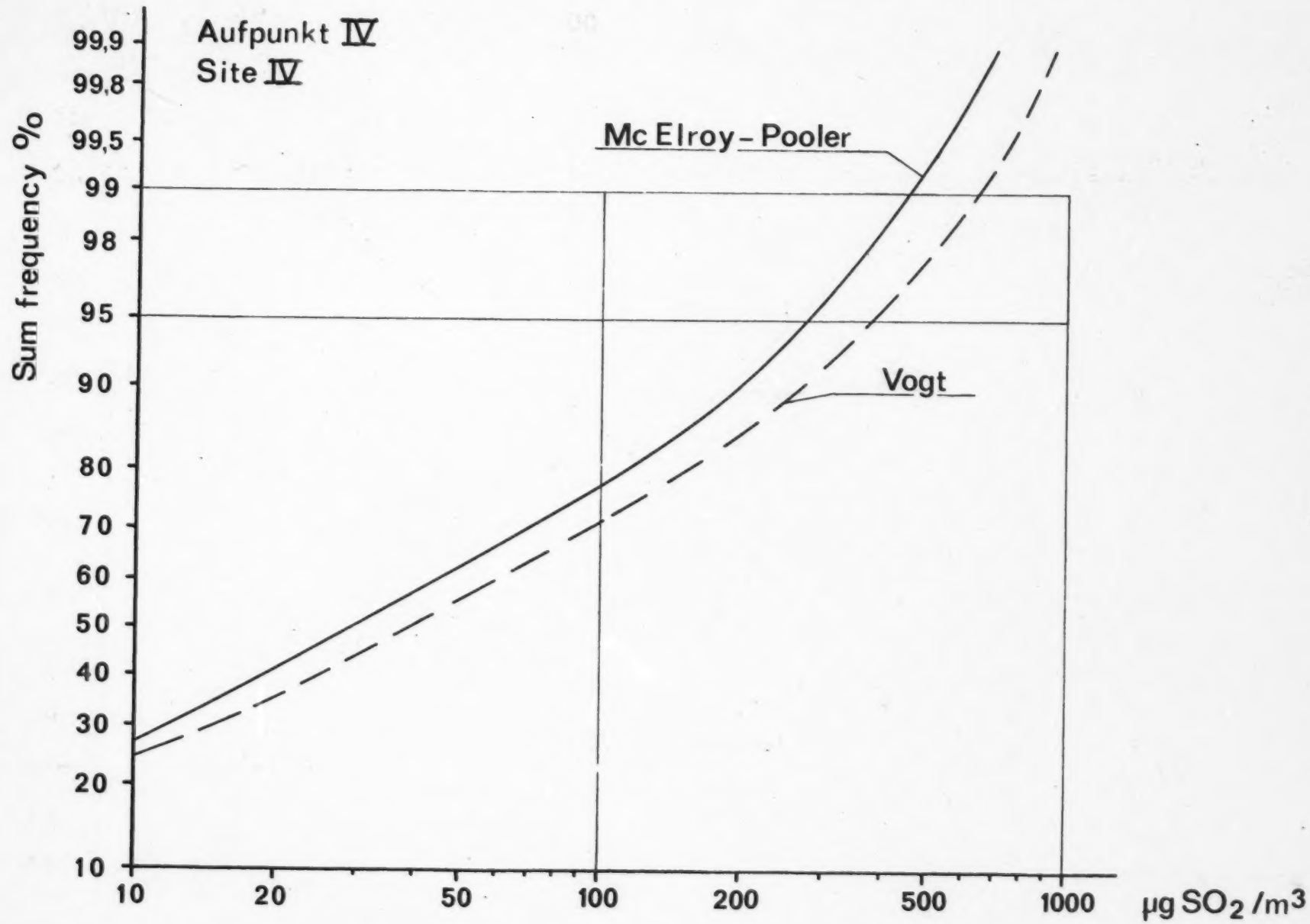

HW=44000
HW=20000
RW=19000
RW45000
5
10
15
20
25
30
35
20
40
60
80
100

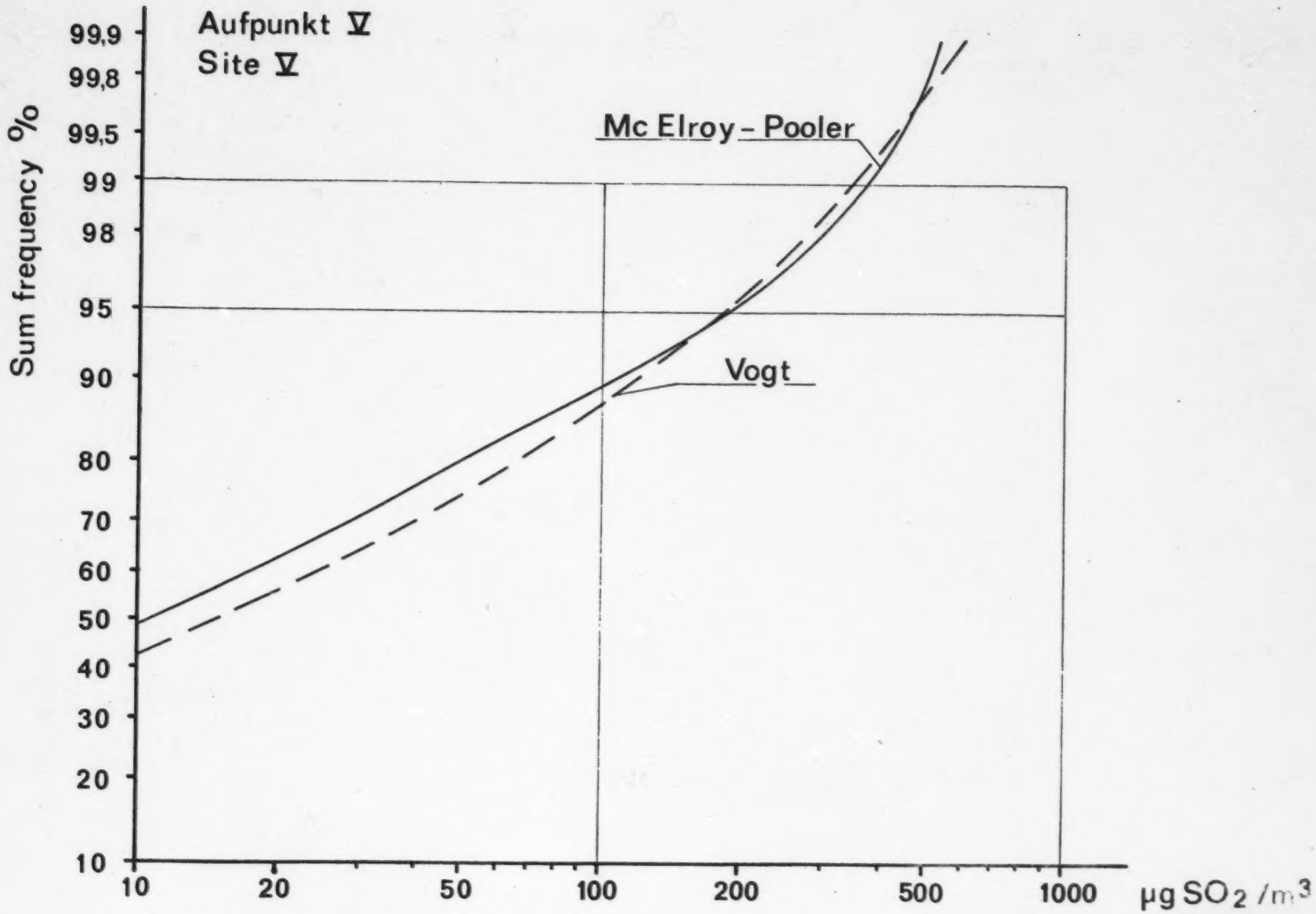
fig. 4

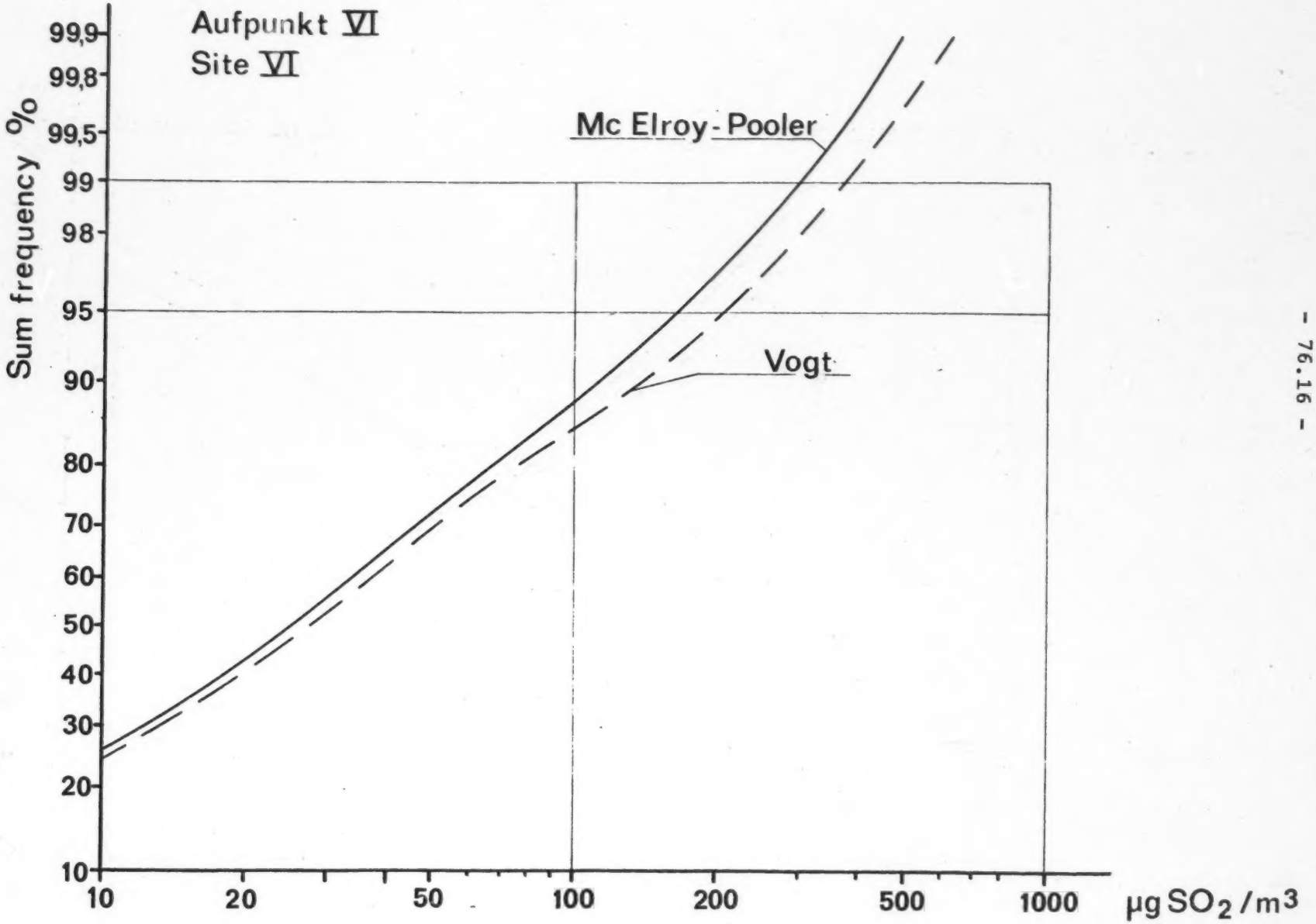

Aufpunkt I
Site I
Sum frequency %
99,9
99,8
99,5
99
98
95
90
80
70
60
50
40
30
20
10
Mc Elroy - Pooler
Vogt
10
20
50
100
200
500
1000
µg SO2 / m3


Aufpunkt II
Site II
Sum frequency %
99,9
99,8
99,5
99
98
95
90
80
70
60
50
40
30
20
10
Mc Elroy - Pooler
Vogt
10
20
50
100
200
500
1000
µg SO2 /m3


Aufpunkt III
Site III
Sum frequency %
99,9
99,8
99,5
99
98
95
90
80
70
60
50
40
30
20
10
Mc Elroy - Pooler
Vogt
10
20
50
100
200
500
1000
µg SO2/m3


Aufpunkt IV
Site IV
Sum frequency %
99,9
99,8
99,5
99
98
95
90
80
70
60
50
40
30
20
10
Mc Elroy - Pooler
Vogt
10
20
50
100
200
500
1000
µg SO2 /m3


Aufpunkt V
Site V
Sum frequency %
99,9
99,8
99,5
99
98
95
90
80
70
60
50
40
30
20
10
Mc Elroy - Pooler
Vogt
10
20
50
100
200
500
1000
µg SO2 /m3


Aufpunkt VI
Site VI
Sum frequency %
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99,8
99,5
99
98
95
90
80
70
60
50
40
30
20
10
10
20
50
100
200
500
1000
µg SO2 /m3
Mc Elroy-Pooler
Vogt

Practical Demonstration of Urban Air Quality Simulation Models

Model Results of

Hanna, Gifford; USA

Application of the ATDL Simple Urban Dispersion Model to Frankfurt, West Germany

by
Steven R. Hanna
and
Franklin A. Gifford, Jr.

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National Oceanic and Atmospheric Administration
Oak Ridge, Tennessee 37830

Abstract

Two versions of the ATDL simple urban dispersion model are applied to estimate average annual SO_2 concentrations in Frankfurt, using data supplied by the NATO/CCMS group. A background concentration of 40 $\mu g/m^3$ is assumed. In the simplest model (χ = background +50 Q/U), area sources are averaged over 16 km^2 grid squares, and a mean wind speed of 2 m/s is used. The factor 50 is based on experience with calculating SO_2 concentrations in the U.S. Contributions from point sources are assumed to be insignificant. Predicted SO_2 concentrations at the six observing stations range from 54 to 125 $\mu g/m^3$, and the correlation between predicted and observed concentrations (obtained by interpolating between observing stations in report N. 6 of NATO/CCMS) is .83. The template of average annual SO_2 concentrations for the Frankfurt area is assumed to be proportional to the area source emissions pattern. Frequency distributions are obtained for each station by assuming that the shape of the distribution curve is the same as the average log-normal shape measured at several U.S. cities.

The second, slightly more complicated version of the ATDL urban dispersion model accounts for individual point sources with emissions greater than 5 kg/hr. Also, advection from upwind area sources is included. However, the resulting concentrations are not much different (correlation .98) from the concentrations predicted by the simpler version, and the correlation between predicted and observed concentrations is .80. This result confirms our earlier conclusion that the simplest model is sufficient for estimating urban pollutant concentrations.

ATDL Contribution File No. 71/12

1. Introduction

We were asked to apply the ATDL urban dispersion model to predict SO_2 concentrations in Frankfurt, West Germany, as part of the Practical Demonstration of Urban Air Quality Simulation Models, in the NATO/CCMS Air Pollution Pilot Study. The input data were supplied in Report N6 by the NATO Committee on the Challenges of Modern Society. The time period of interest is August 1971 to July 1972. Annual average SO_2 concentrations and frequency distributions at six locations were requested, as well as a template for average annual concentrations over the entire Frankfurt region. Measured concentrations at the six stations and results of the applications of other models will be released by the NATO committee at some later date.

In this application, we attempted to stress the simple aspects of the model, in order to provide a more extreme basis for comparison with other models. Our experience has shown that in most applications the simplest model works as well as or better than much more complex models. The simplest version of the ATDL model is

$$\chi = CQ/U \qquad (1)$$

where χ is concentration in $\mu g/m^3$, C is a dimensionless parameter, Q is area source emissions in $\mu g/m^2$ sec, and U is wind speed in m/s (Gifford and Hanna, 1970 and Hanna, 1971). The parameter C,

which is a function mostly of stability, is predicted theoretically to have values of 50, 200, and 600 during unstable, neutral, and stable conditions, respectively. The neutral value is also assumed to apply to averages over time periods of one day or greater. Recently Hanna (1977) verified the theoretical predictions of the diurnal variation of C, using observations of carbon monoxide emissions and concentrations and wind speeds at many stations in the eastern U.S. Gifford and Hanna (1973) calculated the ratio $\chi U/Q = C$ for several cities and found that the annual average C for suspended particles agreed with the theoretical prediction. However the observed C equaled 50 for SO_2 and 700 for CO. We reason that the measured C is low for SO_2 because of removal processes and the fact that SO_2 sources tend to be elevated. Likewise, the measured C is high for CO because of the tendency to locate CO monitors right next to busy highways.

A slightly more complex version of the ATDL model was also applied to the Frankfurt data. In this version (Gifford and Hanna, 1970 and Hanna, 1973) advection from upwind grid squares is accounted for in the formula:

$$\chi = \sqrt{2/\pi}((\Delta X/2)^{1-b}/(aU(1-b))[Q_o + \sum_{i=1}^{N} Q_i((2i+1)^{1-b}-(2i-1)^{1-b})] , \quad (2)$$

where ΔX is the grid size and N is the number of grid squares between the receptor and the upwind edge of the city. The factors a and b appear in the relation

$$\sigma_z = ax^b \qquad (x \text{ and } \sigma_z \text{ in meters}) \qquad (3)$$

For average or neutral conditions, it is assumed that a = .15 and b = .75. A 16 point wind direction rose is used in conjunction with equation (2). Concentrations due to large point sources are calculated separately using the Gaussian plume formula and Briggs'(1969) plume rise formulas.

When applied to annual average emissions and wind speeds, the simple model does not yield a frequency distribution of hourly pollution concentrations. It is possible to generate such a distribution by applying the model hour by hour for a year. But in keeping with our emphasis on simplicity, in this exercise the frequency distribution in Frankfurt is assumed to be similar to those reported by Larsen (1971) for eight U.S. cities. His data show that the cumulative frequencies of hourly SO_2 concentrations in urban areas fall along a straight line when plotted on log-normal graph paper. Agreement with the straight line is best for points within two standard deviations of the geometric mean. The average slope of the line, given by the ratio (16 percent concentration)/(50 percent concentration), equals 2.22. Knowing the geometric mean concentration, the distribution can be estimated by drawing a straight line on log-normal graph paper.

2. Input data

In report N6 it is stated that the average annual wind speed in Frankfurt is 2 m/s. The wind direction frequency

distribution, used in the more complex version of the simple model, is given in Table 1.

Table 1

Wind Direction Frequencies for Frankfurt

Direction	Fraction	Direction	Fraction
N	.081	S	.030
NNE	.148	SSW	.107
NE	.081	SW	.194
ENE	.032	WSW	.094
E	.030	W	.054
ESE	.027	WNW	.032
SE	.022	NW	.027
SSE	.013	NNW	.028

Stabilities are assumed to be similar to those in previous studies; i.e., the average C = 50 for SO_2.

Area source emissions are given in 0.5 km grid squares in report N6. In our application, the published area source emissions are averaged over 4 km grid squares, since we have found that the best correlation between pollutant concentrations and emissions within a surrounding area A occur when A is about 10 km^2. The area source emissions used in this analysis are summarized in Figure 1, where the x-y coordinate system is the same as that used in report N6. Point source emissions are not listed here because their contribution to the total concentration was found to be slight when compared to the area sources.

3. Results of Application of Simpler Model

Calculations of ground level SO_2 concentrations due to a few of the largest point sources were made using the Gaussian plume formula, leading to the conclusion that the contribution due to point sources is usually less than 1 $\mu g/m^3$. Consequently point sources are neglected in this model application.

The contribution to ground level SO_2 concentrations due to Frankfurt area sources is obtained by multiplying the emissions listed in Figure 1 by C/U, or 25 sec/m. Because of the strong industrialization of the western Germany region in which Frankfurt is located, a background must also be included. Best agreement with the magnitude of observed SO_2 concentrations is obtained by assuming a background of 40 $\mu g/m^3$. Predicted SO_2 concentrations for each grid square are given in Figure 2 and isopleths based on these values are given in Figure 3. The six stations for which predictions are made are also shown on the figures. All but station 3 are located near the center of grid squares, and the concentration can be assumed to be equal to that listed in the grid square. The concentration at station 3 is assumed to be given by the average of the four surrounding grid squares. The predicted concentrations are listed in Table 2 along with the predictions of other models. The observed concentrations are best estimates interpolated from data in the N6 report.

Table 2

Model Predictions and Observations of Annual SO_2 Concentration in Frankfurt

Station	Observed $\chi(\mu g/m^3)$	ATDL Simpler Model χ	ATDL More Complex χ	(a) CDM χ	(a) CDM36 χ	(b) Texas χ	(c) Neth. χ	(d) SCAM χ
1	95	97	88	68	71	123	79	72
2	96	125	111	59	60	97	65	57
3	93	116	104	71	76	111	88	75
4	62	67	65	50	53	85	70	47
5	77	54	59	29	30	23	45	21
6	68	70	78	35	37	51	42	38
Correlation between observed and predicted		.83	.80	.70	.68	.61	.56	.67

(a) Turner (1976)
(b) Christiansen and Porter (1976)
(c) Nieuwstadt and Engeldal (1976)
(d) Irwin (1976)

The other model predictions are taken from reports sent to us during the past few months by some of the other research groups participating in the model comparison. The ATDL "more complex" model predictions will be discussed in the next section. The correlations listed in the table show that the simpler ATDL model produces the best correlation ($r = .83$) between observed and predicted concentrations.

Predicted frequency distributions of hourly SO_2 concentrations for the six stations are given in Figure 4. These are based on Larsen's (1971) findings that urban distributions are log-normal and that the ratio of the 16 percent to the 50 percent concentation averages 2.22 for eight U.S. cities. For a log-normal distribution

the geometric mean equals the arithmetic mean (given in Table 2) divided by $\exp(0.5\ \ln^2 2.22)$. The curves in Figure 3 are truncated at ± two standard deviations because of uncertainties in the extreme values.

4. Results of Application of More Complex Model

The more complex model described by equation (2) accounts for advection from upwind grid squares. Also, individual calculations of contributions due to 51 point sources with source strength greater than 5 kg/hr are made. The computer program listed by Hanna (1973) was used to make these calculations, using a grid size of 4 km, a mean wind speed of 2 m/s, and the wind direction frequency distribution in Table 1. A background SO_2 concentration of 40 $\mu g/m^3$ is assumed, as before. The predicted concentrations at each grid square are given in Figure 5, where the number in parentheses is the contribution due to point sources. It is seen that the contribution due to point sources is nearly always a small fraction of that due to area sources, especially in the areas with higher concentrations. The predicted concentrations for the six monitoring stations are listed in Table 2, giving a correlation of .80 between observations and predictions. It is interesting that the simpler model gives the best correlation for these data, although the slight difference is statistically insignificant. We find that this happens consistently, whenever the simple model is compared with more complex models using new sets of urban pollution data. A comprehensive comparison of our model with many others was given by Gifford (1973) at the 4th meeting of the NATO/CCMS group.

5. Conclusions

The average annual SO_2 concentrations predicted by the simple ATDL urban dispersion model are listed in Table 2. The correlation between the predictions and interpolated observations is .83. The template for annual SO_2 concentrations is given in Figure 3, which is directly proportional to the area source emissions template in Figure 1. Point sources were determined to be unimportant in these calculations. Cumulative frequency distributions of hourly SO_2 concentrations are given in Figure 4, based on the assumptions of a log-normal distribution with a slope determined by SO_2 data from U.S. cities.

6. Acknowledgements

Much of the Frankfurt data was relayed to us by Bruce Turner and John Irwin of the U.S.E.P.A. This research was conducted under an agreement between the National Oceanic and Atmospheric Administration and the Energy Research and Development Administration.

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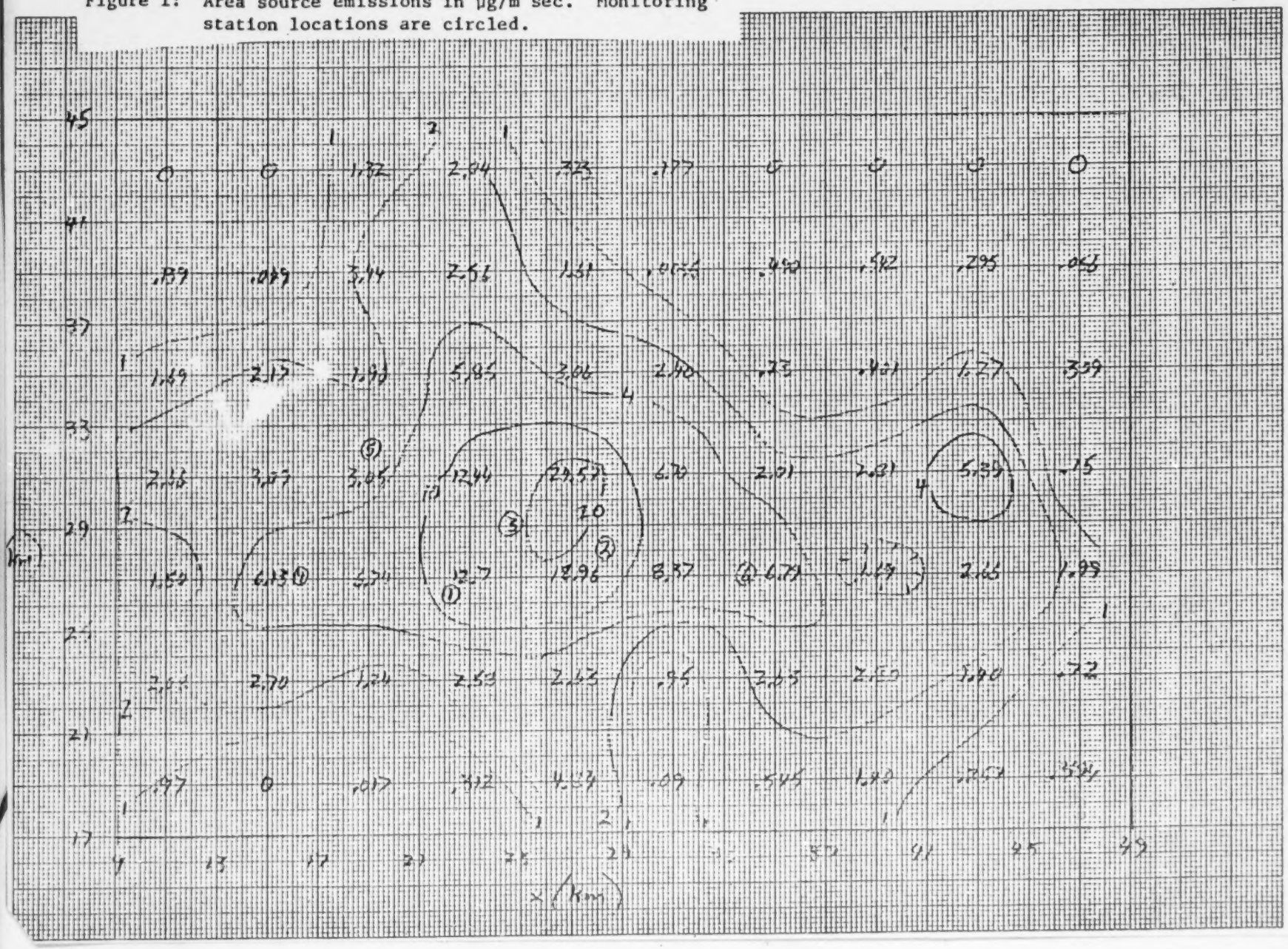
Turner, D. B., 1976: The Application of the CDM (Climatological Dispersion Model) to the NATO Common Data Base for Frankfurt, U.S. EPA, Research Triangle Park, NC, 27711, 9 pp.

Figure 1: Area source emissions in $\mu g/m^2 sec$. Monitoring station locations are circled.



Monitoring station locations are circled.

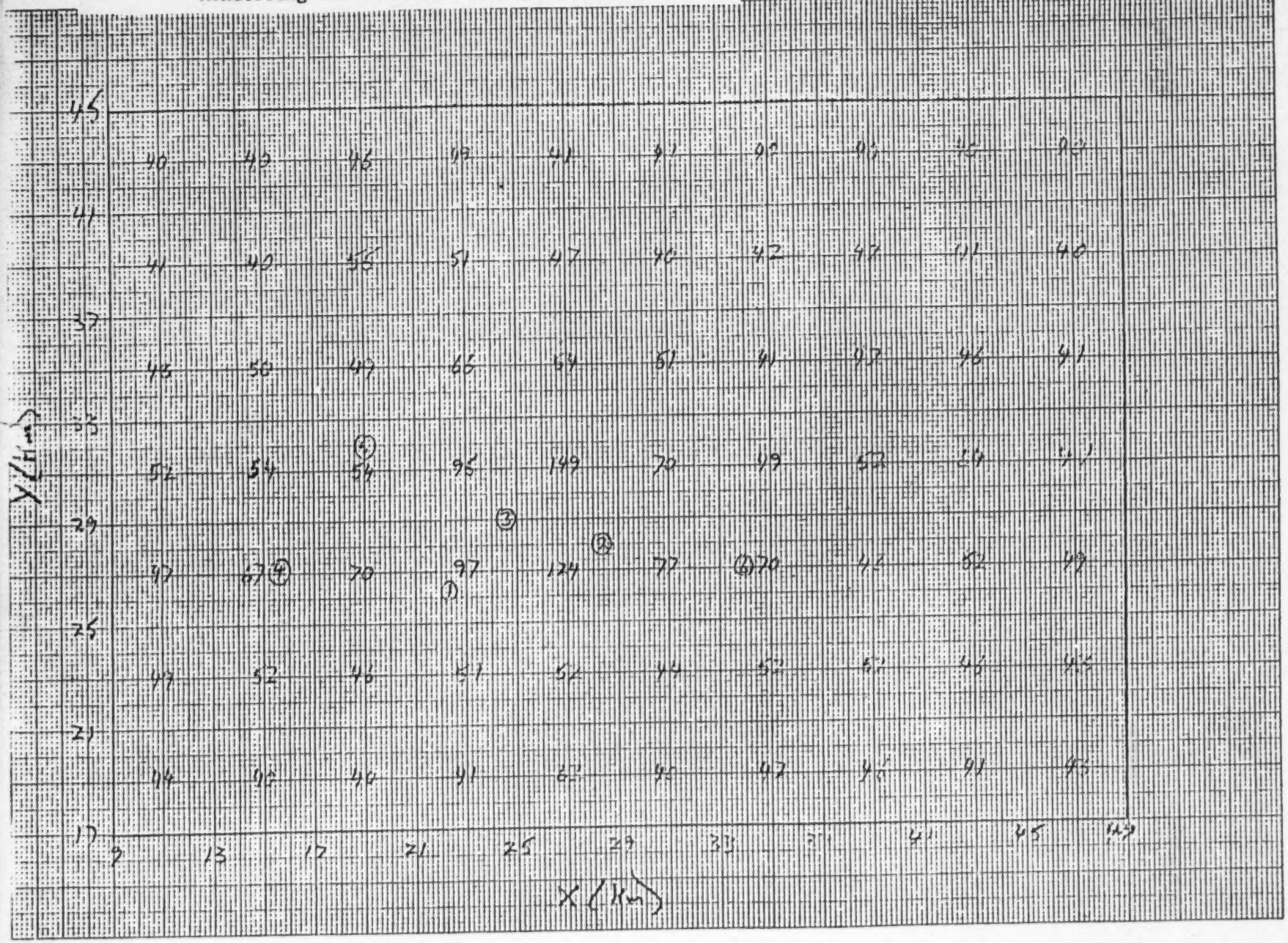
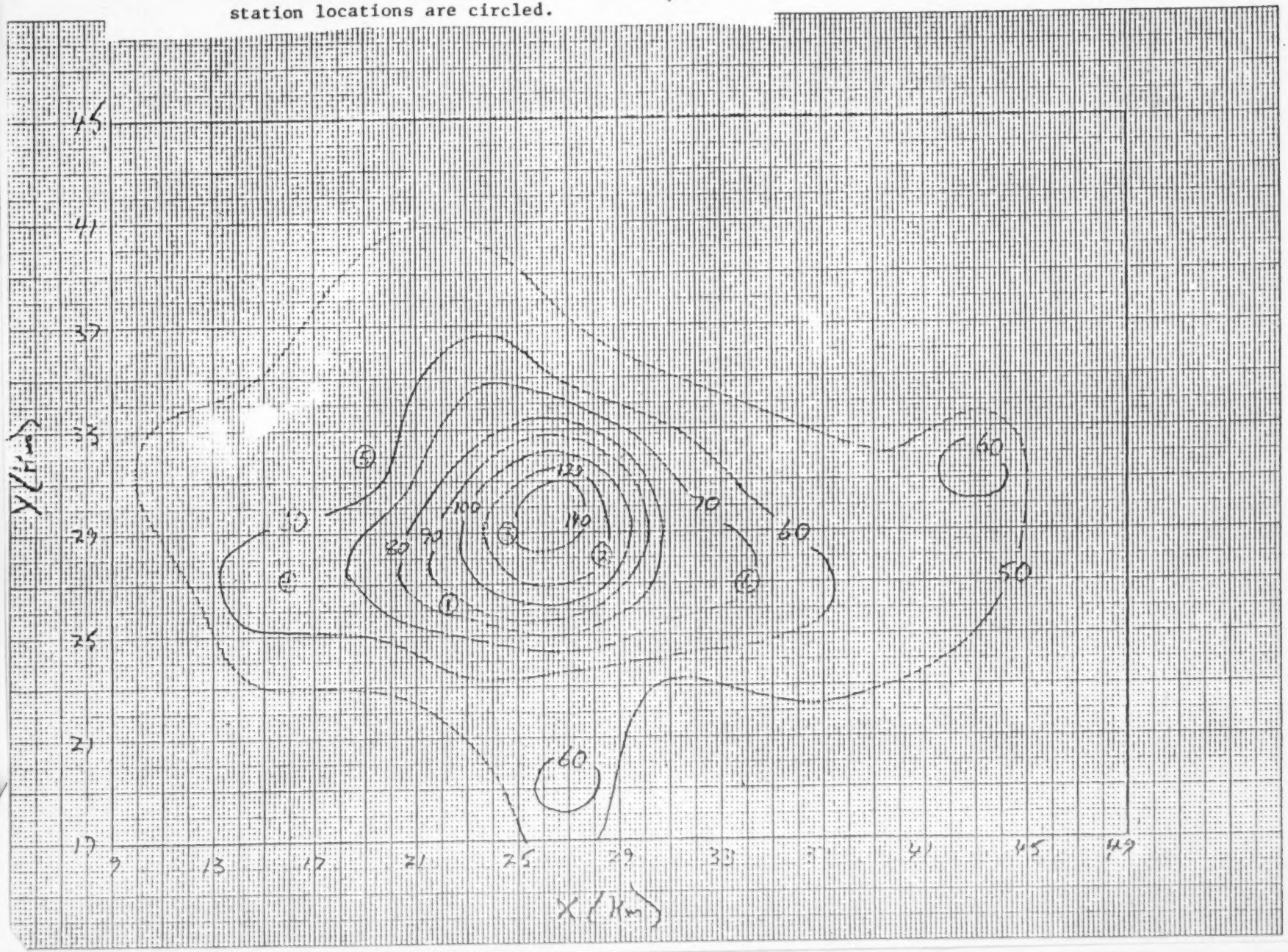


Figure 3: Isopleths of annual average SO_2 concentrations, drawn from the data in F ıre 2. Monitoring station locations are circled.



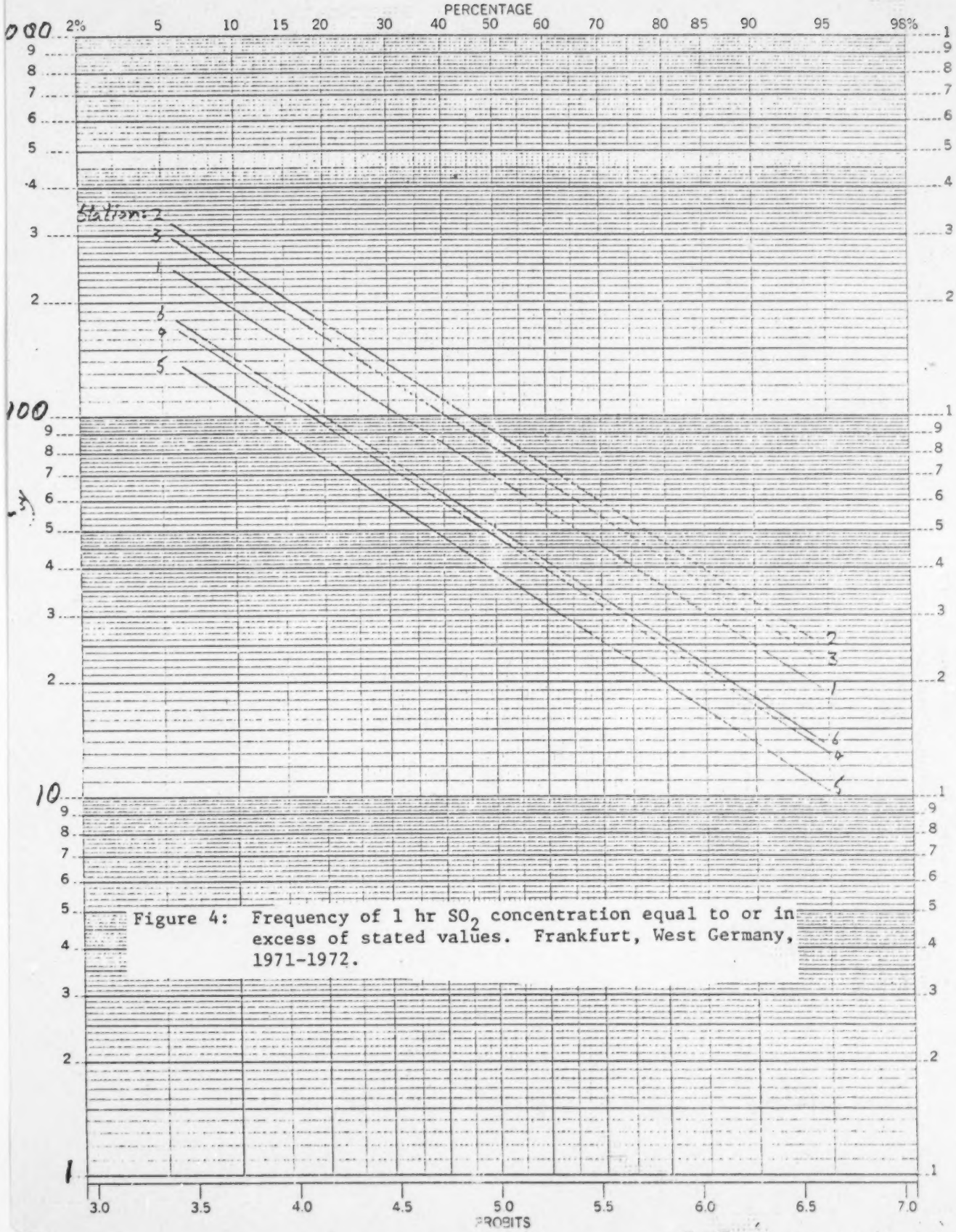
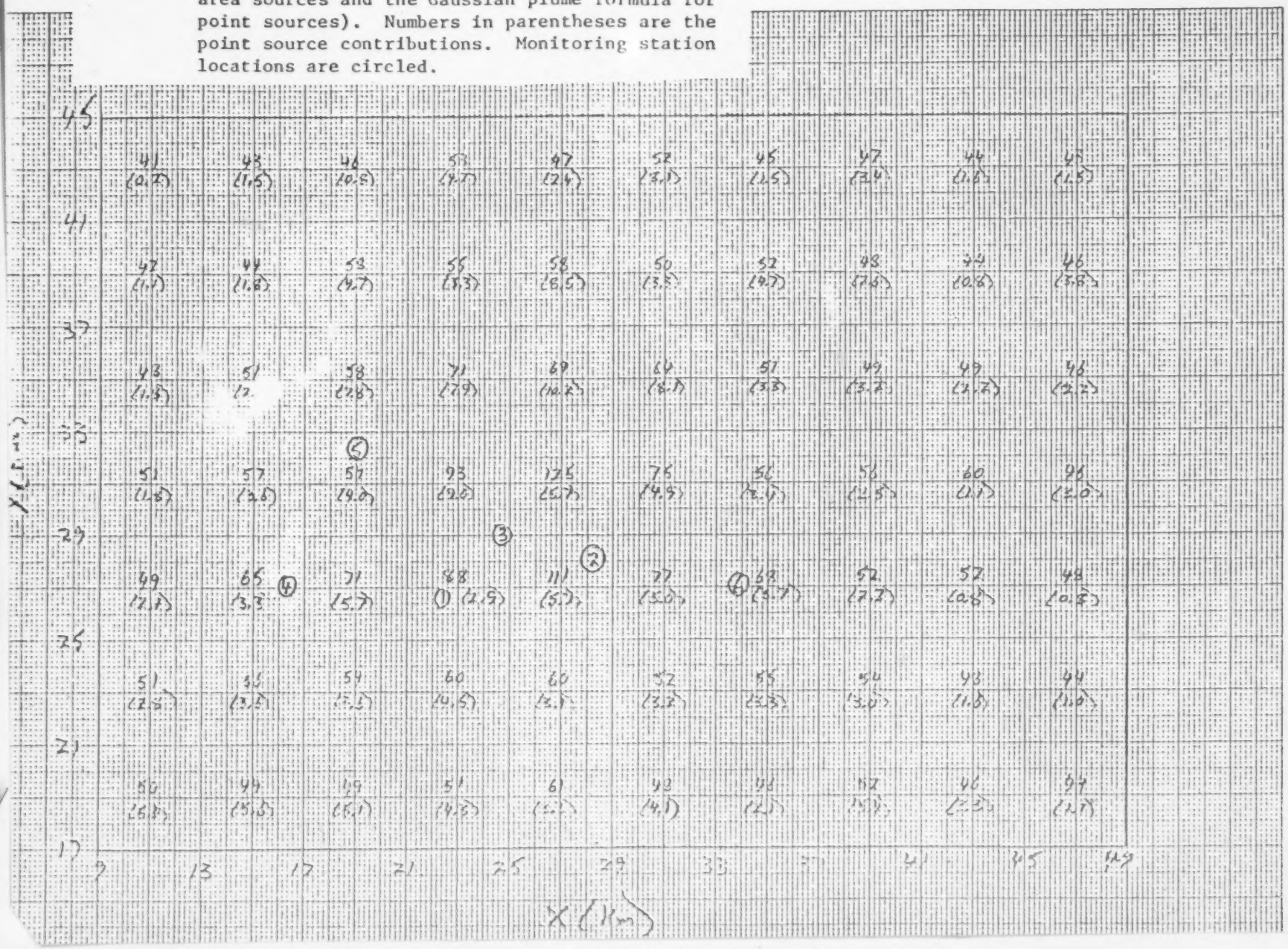


Figure 4: Frequency of 1 hr SO_2 concentration equal to or in excess of stated values. Frankfurt, West Germany, 1971-1972.

Figure 5. Annual average SO_2 concentrations predicted using the ATDL computer model (bas ' on equation (2) for area sources and the Gaussian plume formula for point sources). Numbers in parentheses are the point source contributions. Monitoring station locations are circled.



ANNEX I

Names and Addresses of Panel Members (as of Fall 1978)

R. D. Bauman	Environmental Protection Agency (OAQPS - SASD - ESB - MD - 12) Research Triangle Park USA - 27711 North Carolina
A. Berger	Institut d'Astronomie et de Géophysique Université Catholique de Louvain 2, Chemin du Cyclotron B - 1348 Louvain la Neuve
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F. Gerold	TÜV Rheinland Postfach 10 17 50 D - 5000 Köln 1
B. Gutsche	Institut für Geophys. Wissenschaften Freie Universität Thielallee 50 D - 1000 Berlin 33
K. E. Joerss	Umweltbundesamt Bismarckplatz 1 D - 1000 Berlin 33
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ANNEX II

NATO/CCMS Documents on the First Air Pollution Pilot Study (available at: NATO/Committee on the Challenges of Modern Society, NATO Headquarters, Brussels, Belgium)

AIR POLLUTION (No. 5)

Proceedings of the 2nd Meeting of the Expert Panel on Air Pollution Modeling, (26 - 27 July 1971, Paris, France). Out of stock

AIR POLLUTION (No. 6)

Guidelines to Assessment of Air Quality (Revised)

APPENDIX A	Assessment of Air Quality in Ankara (February 1973)
APPENDIX B	Assessment of Air Quality in St. Louis (February 1973)
APPENDIX C	Assessment of Air Quality in Frankfurt (June 1974)
APPENDIX D	Assessment of Air Quality in Oslo (February 1973)
APPENDIX E	Assessment of Air Quality in the South Holland Region (December 1973)

AIR POLLUTION (No. 7)

Quality Criteria for Sulphur Oxides (November 1971). Out of stock

AIR POLLUTION (No. 8)

Air Quality Criteria for Particulate Matter (November 1971). Out of stock

AIR POLLUTION (No. 10)

Air Quality Criteria for Carbon Monoxide (June 1972)

AIR POLLUTION (No. 12)

Control Techniques for Sulphur Oxide Air Pollutants (October 1973)

AIR POLLUTION (No. 13)

Control Techniques for Particulate Air Pollutants
(October 1973)

AIR POLLUTION (No. 14)

Proceedings of the 3rd Meeting of the Expert Panel on Air Pollution Modeling
(2 - 3 October, 1972, Paris)

AIR POLLUTION (No. 15)

Air Quality Criteria for Nitrogen Oxides (June 1973)

AIR POLLUTION (No. 18)

Control Techniques for Carbon Monoxide Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 19)

Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 20)

Control Techniques for Nitrogen Oxide Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 29)

Air Quality Criteria for Photochemical Oxidants and Related Hydrocarbons (February 1974)

AIR POLLUTION (No. 30)

Proceedings of the 4th Meeting of the Expert Panel on Air Pollution Modeling, (28 - 30 May 1973, Oberursel, Germany)

AIR POLLUTION (No. 33)

Final Report (May 1974)

AIR POLLUTION (No. 35)

Proceedings of the 5th Meeting of the Expert Panel on Air Pollution Modeling (4 - 6 June 1974, Roskilde, Denmark)

AIR POLLUTION (No. 41)

First Follow-up Report (December 1975)

AIR POLLUTION (No. 50)

Second Follow-up Report (December 1976)

AIR POLLUTION (No. 67)

Third Follow-up Report (November 1977)

AIR POLLUTION (No. 96)

Fourth Follow-up Report (October 1978)

AIR POLLUTION (No. 6, Appendix C revised)

Assessment of Air Quality in Frankfurt (December 1977)

ANNEX III

NATO/CCMS Documents on the Pilot Study on Air Pollution Assessment Methodology and Modeling
(available at: NATO/Committee on the Challenges of Modern Society, NATO Headquarters, Brussels, Belgium)

Air Pollution (No. 42)

Proceedings of the 6th International Technical Meeting on Air Pollution Modeling and its Application
(24 - 26 September 1975, Frankfurt/Main, Germany)

Air Pollution (No. 51)

Proceedings of the 7th International Technical Meeting on Air Pollution Modeling and its Application
(7 - 10 September 1976, Airlie House, USA)

Air Pollution (No. 70)

Bibliography on Grey Literature on Air Quality Modeling, Part I (Applied Models) (October 1977)

Air Pollution (No. 71)

Air Quality Management Systems (AQMS) (October 1977)

Air Pollution (No. 88)

Bibliography on Grey Literature on Air Quality Modeling, Part II (New Modeling Techniques) (October 1978)

Air Pollution (No. 89)

Glossary of Terms Generally Used in Air Pollution Assessment Methodology and Modeling (October 1978)

Air Pollution (No. 80)

Proceedings of the 8th International Technical Meeting on Air Pollution Modeling and its Application
(20 - 23 September 1977, Louvain-la-Neuve, Belgium)

Air Pollution (No. 99)

Introduction to Air Quality Modeling (October 1978)

Air Pollution (No. 100)

Air Pollution Emissions Projecting (October 1978)

Air Pollution (No. 101)

Uses and Needs for Air Quality Modeling (May 1979)

Air Pollution (No. 102)

Fundamentals for the Application of a Gaussian Plume Model
(April 1979)

Air Pollution (No. 104)

Air Pollution Emissions Inventory Systems
(October 1978/July 1979)

APPENDIX A: Emissions Inventory in Belgium
APPENDIX B: Emissions Inventory in Canada
APPENDIX C: Emissions Inventory in Germany, Federal Republic of
APPENDIX D: Emissions Inventory in The Netherlands
APPENDIX E: Emissions Inventory in Norway
APPENDIX F: Emissions Inventory in the United States of America

Air Pollution (No. 106)

Practical Demonstration of Multiple Source Urban Air Quality Modeling (Gaussian Plume) (August 1979)

Air Pollution (No. 71, Revised)

Air Quality Management Systems (AQMS) (April 1979)

Air Pollution (No. 105)

FINAL REPORT (October 1979)

Air Pollution (No. 103)

Proceedings of the 9th International Technical Meeting on Air Pollution Modeling and its Application
(28 - 31 August, 1978, Toronto, Canada)

Air Pollution (No. 108)

Proceedings of the 10th International Technical Meeting on Air Pollution Modeling and its Application
(23 - 26 October, 1979, Roma, Italy)

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